STATIC STANDING BALANCE AND STRENGTH MEASUREMENTS BEFORE AND AFTER TWO DIFFERENT GROUP EXERCISE INTERVENTIONS IN INDEPENDENT LIVING OLDER ADULTS

by

Bader Ali Alqahtani

Bachelor of Science, Physical Therapy, King Saud University, 2009

Master of Science, Physical Therapy, University of Pittsburgh, 2012

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This dissertation was presented

by

Bader Ali Alqahtani

It was defended on

May 8, 2017

and approved by

Jennifer S. Brach PT, PhD, Associate Professor, Department of Physical Therapy

Susan L. Greenspan, MD, Professor, Department of Medicine

Subashan Perera, PhD, Professor, Department of Medicine

Susan L. Whitney PT, PhD, Professor, Department of Physical Therapy

Dissertation Advisor

Patrick J. Sparto, PT, PhD, Associate Professor, Department of Physical Therapy

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Bader Ali Alqahtani, PhD

University of Pittsburgh, 2017

Purpose: The aims of this dissertation were to examine, in older adults: 1) the test-retest reliability of static standing balance performance using an accelerometer and lower extremity strength performance using a uniaxial load cell device; 2) the validity of balance and strength measurements at baseline with different mobility measurements; and 3) the effect of two different exercise programs on standing balance and lower extremity muscle strength.

Participants: Thirty-eight participants were enrolled in the reliability testing (89% female, mean age 76 ± 7 years), and a total of 131 subjects (85% female, mean age 80 ± 8 years) were enrolled in the experimental study.

Methods: For the balance assessment, an accelerometer was used to collect acceleration data in the anterior-posterior and medial-lateral directions for different standing balance conditions. In addition, lower extremity muscle strength measurements were assessed with a portable load cell for three consecutive trials. Clinical measures of mobility were concurrently tested. Test-retest reliability was assessed over two testing visits occurring one week apart, using the intraclass correlation coefficient. Spearman's rank correlation coefficient was used to test convergent validity at baseline for the whole sample. A linear mixed model was used to examine the effect of the “On the Move” and standard of care group exercise programs on standing balance and lower extremity muscle strength.

Results: Both balance and muscle strength performance showed good to excellent test-retest reliability using the accelerometer and uniaxial load cell device, respectively. The balance and measures were most strongly correlated with the Short Physical Performance Battery, and the strength measures with the repeated chair stands test. Both exercise interventions resulted in a significant change in both balance accelerometry measures and lower extremity muscle strength when compared to a waitlist control group, but did not differ from each other.

Conclusion: The dual-axis accelerometer and uniaxial-load cell provide a reliable method for testing standing balance and lower extremity muscle strength, respectively in older adults living independently in the community. Participation in either group exercise intervention would result in improvement in both standing balance and lower extremity strength as compared to not receiving any exercise.

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PREFACE

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LIST OF ABBREVIATIONS

AP	Anteroposterior
EO	Eyes Open
EC	Eyes Closed
F8WT	Figure of 8 test
GES	Gait Efficacy Scale
GRS	Global Rating of State in balance
ICC	Intraclass Correlation Coefficient
ILF	Independent Living Facilities
mG	milli-Gravitational
mG/s	milli-Gravitational per second
ML	Mediolateral
MCID	Minimal Clinically Important Difference
NPL	Normalized Path Length
OTM	On the Move group exercise program
OTM-IL	On the Move- Immediate Leader
OTM-WS	On the Move- Wait Staff
PF	Plantarflexion
RMS	Root Mean Square
RCC	Residential Care Communities
STD	Standard group exercise program

STD-IL Standard- Immediate Leader

STD-WS Standard- Wait Staff

SEM Standard Error of Measurement

SPPB Short Physical Performance Battery

6MWT Six Minute Walk Test

1.0 INTRODUCTION

The population of the United States will age dramatically over the next several decades. In 2050, the size of the population aged 65 and over is projected to be about 83.7 million, almost double the estimate of 43.1 million in 2012,[1] and will represent nearly 20% of the total U.S. population.[2] With the increased number of older adults over the age of 65, the number of falls, fall-related injuries and deaths, and associated treatment costs will also rise significantly.[3]

In 2012, approximately 2.1 million people lived in long-term care facilities in the US. Two-thirds lived in nursing homes and one-third resided in residential care communities (RCC).[4] A RCC is defined as a facility that provides room, board with at least two meals a day, and help with personal care such as bathing and dressing or health-related services, such as medication management.[4,5] The residential care communities include both assisted living and independent living facilities. The difference between the two types of facilities is that the assisted living facility offers an advanced level of care compared with the independent living facilities.[6] Older adults residing in long-term care facilities are at greater risk of falling and sustaining an injury compared to community dwellers.[7]

Falls are among the most serious public health problems facing older adults.[8] In persons over 65 years, more than one-third of community-dwelling adults fall each year, and half will experience recurrent falls.[8] Falls have been associated with high rates of morbidity, reduced function, decreased quality of life, and premature nursing home and hospital admissions. About

20-30% of people who fall suffer injuries that lead to decreased mobility that restricts subsequent independence.[7,9,10] Every year about 250,000 older adults are admitted to the hospital for hip fractures, which is one of the common complications of falls in older adults.[11] Falls are responsible for 87% of all fractures in older adults,[12] leading to a medical cost of $23.3 billion every year.[13]

Normal aging is related to declines in several body systems including cardiovascular, sensory, musculoskeletal, and cognitive function, all of which have been associated with increased risk of falling.[14–16] It is well documented that aging itself also is associated with a decrease in muscle strength, balance, and functional mobility.[17] Maintaining mobility is important for active aging and in preserving community independence; it is also related to better health status and quality of life.[18] Preserving postural stability is also imperative for older adults to perform activities of daily living safely and independently within their society and thereby avoiding falls.[19] Lower-extremity muscle weakness and balance impairment are two of the many risk factors that have been associated with mobility limitations and falls in older adults.[7,20]

The risk of falls can be altered by lifestyle changes, such as exercise and physical activity.[21,22] Therefore, implementing well-designed exercise interventions to improve mobility and decrease falls is necessary. A wide range of exercise interventions have been developed and are intended to improve mobility and decrease the risk of falling in community-dwelling older adults.[23] However, each of these interventions is different in design, methodologies, and approach. Exercise interventions that aim to enhance postural control and mobility have consisted of mostly multifactorial approaches, concentrating on addressing the impairment of the involved systems (i.e. musculoskeletal or sensory).[24,25] Results from these interventions showed modest improvements in walking. Recently, more functional-based exercises and training have emerged.

A contemporary training concept to improve walking and mobility focuses on task-oriented training through implementing motor learning approaches, in which individuals practice walking-related tasks. A number of studies that have investigated task-oriented walking exercise programs have indicated an improvement in walking outcomes in people with stroke.[26] A new task-oriented motor learning group-based exercise has been developed called *On the Move* (OTM), which aims to improve walking and promote independence in older adults by incorporating timing and coordination components. Preliminary data have shown a significant improvement in walking and mobility measures in people who received the OTM exercise program compared to a standard group exercise program.[27] The OTM program includes different walking and stepping exercises that may encourage lower extremity muscles to coordinate activation in order to swing, load, and unload the stepping limb. It has not been investigated if the OTM program affects some of the contributing factors related to fall risk. Therefore, one of the aims of the study is to assess changes in standing balance and lower extremity strength that occur after participation in the OTM program, in comparison with a standard group exercise program and a waitlist control group.

Because maintaining body balance and mobility is important to successful aging, the assessment of balance and muscle strength is important for identifying older adults who are at high risk of falling, and then developing an exercise intervention to address any impairments. Reliable and valid assessment instruments are necessary to obtain consistent and repeatable measurements for static standing balance and muscle strength. Several methods have been developed to assess balance in older adults. Currently, the most common methods to examine balance in clinical settings include performance-based measures. However, performance based measures have been shown to have examiner's bias,[28] suffer from floor and ceiling effects,[29] cover limited aspects of balance, and often lack the sensitivity to detect small changes in balance.[30] These drawbacks are major concerns for both clinicians and researchers who treat balance impairments and investigate the effectiveness of different balance interventions.

Over the last two decades, quantitative assessments of postural sway during standing using tools such as force plates have been used to assess balance and identify postural instability in older adults.[31] Various studies have demonstrated good to excellent reliability for recording postural sway with the use of force plates.[32,33] However, due to their cost, required space, and lack of portability, their clinical utility and employment in community settings has been limited.

Recent technological advancements have provided an alternative quantitative method to assess balance that is inexpensive and portable by using body-worn accelerometers. Accelerometers are used to quantify postural sway during standing, and have been shown to have the ability to discriminate between test conditions that require different levels of postural control, between fallers and non-fallers, and young versus older adults.[34–38] Assessing postural stability by using accelerometers has been applied to different populations including people with Parkinson disease,[39] multiple sclerosis,[40] and with community-dwelling older adults.[41,42]

The current gold standard method to measure lower extremity muscle strength is using computerized isokinetic dynamometry.[43] The high financial and time costs plus the non-portability are drawbacks that limit the application of computerized isokinetic dynamometry in independent living facilities. Another method to assess strength in clinical settings is manual muscle testing. Although it is the most frequently used technique to quantify muscle strength in the clinic and is easy to use, it lacks sensitivity and responsiveness, is susceptible to examiner's error, and is subject to a ceiling effect.[44,45] Handheld dynamometers have been used in different settings to objectively quantify muscle strength. Even though portable handheld dynamometry has been proven to be accurate, valid, and reliable in different populations, it has some important limitations, such as difficulty in stabilizing the body part, and the reading is influenced by the strength of the examiner especially for larger muscles.[46,47] The concept of using a simple strain-gauge uniaxial load cell device has been proposed before but it has not been used with older people who live in community settings.[48] A uniaxial load cell device provides an interesting alternative as it is an easy and reliable way to overcome the aforementioned drawbacks and quantify muscle strength in different settings.

To bridge the gap between expensive and immobile instruments and task-based measures, and by taking advantage of technological advancements in accelerometers and load cells, postural stability and muscle strength can be quantified portably and inexpensively outside of a lab setting. These tools can serve understudied populations, such as people living in community settings, who may have difficulty getting transportation to research labs, resulting in limited access to this population.[49] Before implementing these inexpensive and portable instruments, it is important to establish the validity, reliability, and the minimal clinically important difference of balance and strength measurements so that clinicians and researchers can identify changes that are important to an individual. Another aim of this study was to examine the test–retest reliability and validity of balance and lower-extremity strength measurements, and to determine the minimal clinically important difference of these measurements after an exercise program.

These objectives will be accomplished by measuring static standing balance and lower extremity strength in residents of independent living facilities, senior housing sites, and senior community centers before and after they receive exercise interventions to promote mobility, as an ancillary study to a PCORI-funded research grant. The primary intervention of interest is the OTM program. The OTM program will be compared with a standard exercise intervention. Subjects will be allocated to either the OTM exercise group or standard exercise group based on cluster randomization of the study sites, and then after the first baseline testing, subjects in both intervention arms again will be randomly assigned to either the wait list control group or exercise group. For each intervention, half of the subjects will start the exercise intervention immediately for 12 weeks, and the other half will have a 12-week wait period before starting the intervention. In the first 12-weeks, exercise interventions will be delivered by exercise leaders who have training and experience in administering exercise programs. A staff activity employee from each independent living facility will be trained to deliver the exercise program for the wait list exercise groups during the second 12-week period. Reliability data will be collected one week after one of the study visits in a subsample of subjects.

1.1 SPECIFIC AIMS AND HYPOTHESES

1.1.1 Specific aim 1

To examine the psychometric properties of balance accelerometry and lower extremity strength measurements in independent living older adults.

First, the test-retest reliability of balance accelerometry and lower extremity strength measurements will be assessed one week apart. Then, the convergent validity of balance accelerometry and lower extremity strength measurements will be examined with different mobility measurements such as the Six-Minute Walk Test (6MWT), gait speed, Figure-of-8 Walk test (F8WT), Short Physical Performance Battery (SPPB), Gait Efficacy Scale (GES), and repeated chair stands test. Validity of the measurements will be examined cross-sectionally, by calculating the correlation of balance and strength measurements with the mobility measurements at the initial baseline assessment (BL-1).

Hypothesis 1.1:

At the initial baseline assessment, participants who have greater lower extremity strength and better balance performance will show a greater gait speed and SPPB, lesser time to complete F8WT and repeated chair stands test, greater walking confidence, and greater walking distance indicated by the 6MWT.

The third part of the first specific aim is to estimate the minimal clinically important difference (MCID) for balance accelerometry and lower extremity strength measurements, using a range of anchor-based and distribution-based methods in independent living older adults.

1.1.2 Specific aim 2

Primary: To evaluate the effect of the “On The Move” exercise program on standing balance performance and lower extremity strength in knee extension, hip abduction, and ankle plantarflexion in independent living older adults. Performance will be compared to a standard exercise program, and also to a wait list control group.

Secondary: To examine the effect of the standard exercise program on standing balance performance and lower extremity strength in knee extension, hip abduction, and ankle plantarflexion in comparison with wait list control group.

Primary hypotheses:

Hypothesis 2.1: OTM-IL vs. STD-IL

There will be a significant difference in the magnitude of change in balance performance (improvement), but not in the muscle strength, from the baseline assessment (BL-1) to the 12-week post-intervention assessment, between the OTM immediate (I) exercise group conducted by a study leader (L) and the standard (STD) immediate exercise group conducted by a study leader.

OTM-IL: BL-1 ◆—— 12-week OTM exercise program ——◆ Post-intervention

STD-IL: BL-1 ◆—— 12-week standard exercise program ——◆ Post-intervention

Hypothesis 2.2: OTM-IL vs. All Wait list controls

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the OTM immediate exercise group compared to the combined wait list control groups.

OTM-IL: BL-1 ◆—— 12-week OTM exercise program ——◆ Post-intervention

All Wait list: BL-1 ◆—— 12-week waiting period ——◆ BL-2

Secondary hypotheses:

Hypothesis 2.3: STD-IL vs. All Wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by an exercise leader, compared to wait list control group.

STD-IL: BL-1 ◆—— 12-week standard exercise program ——◆ Post-intervention

All Wait list: BL-1 ◆—— 12-week waiting period ——◆ BL-2

Hypothesis 2.4: STD-IL vs. STD-WS

There will be a significant difference in the magnitude of change in balance performance and muscle strength from the baseline assessment to the 12-week post-intervention assessment, between the standard exercise group when delivered by an exercise leader and the standard exercise group when delivered by staff (S) activity personnel, after being on the wait list (W).

STD-IL: BL-1 ◆—— 12-week standard exercise program ——◆ Post-intervention

STD-WS: BL-2 ◆—— 12-week standard exercise program ——◆ Post-intervention

Hypothesis 2.5: STD-WS vs. All wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by staff activity personnel, compared to wait list control group. For this comparison, there were some subjects who participated in both groups, and that was accounted for in the statistical analysis.

STD-WS: BL-2 12-week standard exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

2.0 BACKGROUND AND SIGNIFICANCE

2.1 AGING AND MOBILITY

The percentage of older adults in the US over 65 years will increase dramatically in the next several decades. In 2050, the size of the population aged 65 and over is projected to be about 83.7 million, almost double the estimation of 43.1 million in 2012.[1] Also, approximately 20% of the total U.S. population will be aged 65 and over in 2050.[2] These statistics represent substantial growth in the older population, as well as increased life expectancies. In the United States, the average life expectancy at age 65 was 15.2 years in 1972, and in 2013 a 65 year old person had an average life expectancy of 19.3 years.[1]

The maintenance of mobility is important for active aging and community independence; it is also related to better health status and good quality of life.[18] One definition of mobility is the ability of a person to safely walk independently or by using an assistive device from one place to another.[18] Mobility limitations increase with aging and are usually the first mark of functional decline.[50] Approximately one-third of individuals 65 years or older report difficulty in walking three blocks.[51] Difficulty walking is associated with loss of independence and decreased quality of life in older adults[52,53], and has been related to decreased lower extremity muscle strength[54–56] and loss of balance.[19,56] Moreover, performance of activities of daily living declines with aging. For instance, in 2005, about 18% of people aged 65 and older had difficulty in performing one or more activities of daily living (ADLs), with 12% reporting difficulty in one or more instrumental activities of daily living (IADLs).[57]

The cost of health care increases as older adults' mobility decreases. Older adults who develop walking difficulties annually cost an additional 3 billion dollars per year.[58] In addition, older adults who have difficulty with walking and/or balance are also at high risk of falling.[46] Maintaining mobility by preventing or delaying the onset of walking difficulty could preserve older adults' independence and decrease healthcare costs.[45]

2.2 LONG-TERM CARE AND INDEPENDENT LIVING FACILITIES

In 2012, approximately 2.1 million people lived in long-term care (LTC) facilities in the US. Two-thirds lived in nursing homes and one-third resided in residential care communities (RCC).[4] An RCC is defined as a facility that provides room, board with at least two meals a day, and help with personal care such as bathing and dressing or health-related services, such as medication management.[4] The residential care communities include both assisted living and independent living facilities. The difference between the two types of facilities is that the assisted living facility offers an advanced level of care compared with the independent living facilities.[6] Older adults residing in long-term care facilities are at greater risk of falling and sustaining an injury compared to community dwellers.[7] The incidence of falls and falls-related injuries are common among people in residential care facilities.[61] The higher prevalence of frailty makes older adults in the LTC facilities more prone to experience a fall and its consequences, compared with people who are community ambulators.[61] The measurement of risk factors for falling, in particular balance and strength, is relatively lacking in LTC facilities, compared to measurement in community dwelling older adults.

2.3 AGING AND STANDING BALANCE

2.3.1 Contribution of sensory systems (visual, somatosensory, and vestibular)

In many older adults, the process of aging is inevitably associated with mobility limitations and changes in postural control.[62] The balance system consists of and emerges from an interaction of sensation (somatosensory, visual, and vestibular), central nervous system processing and motor responses.[63,64] In order to maintain balance and postural control, an integration of the somatosensory, visual, and vestibular systems is required.[62,65] A progressive decline in the function of the sensory systems is associated with normal aging.[66–68] This decline can result in postural instability, a major cause of falling in elderly people.[69] In order to understand how changes in the sensory systems contribute to posture and standing balance decline with aging, a review of these systems is necessary.

Somatosensory:

The somatosensory system plays a substantial role in postural control, in order to maintain a normal, quiet stance and to safely perform most activities of daily living.[70,71] Somatosensory inputs gather information from receptors in muscles, joints, and skin, about the position of body segments and movement in space. These receptors include the proprioceptors, which consist of muscle spindles, Golgi tendon organs, and joint receptors. Cutaneous mechanoreceptors, which are involved in sensation of touch, pressure and vibration, work with the proprioceptors to accurately detect body position in space.[72] Deterioration in somatosensory function has been associated with aging and is an important contributor to postural instability and falls in the elderly.[73]

The muscle spindles play a crucial role in detecting muscle length and changes in muscle length, and then provide this information to the nervous system to help regulate muscle length during joint movements.[74] Various researchers have suggested that morphologic changes happen to the muscle spindles as we age.[75,76] An increase in muscle spindle capsule thickness; a decrease in number of intrafusal fibers[75,77]; and a diminished sensitivity of muscle spindles was clear with aging.[74,78] These deteriorations result in desensitization of the muscle spindle.[79] As a result, the aging-related reduction in the muscle spindles afferent input has an impact on the control of muscle's length and velocity of contraction and hence the ability of older adults to overcome balance threats.[80,81]

Other organs that contribute to proprioception input are the Golgi tendon organ (GTO) and joint receptors, which provide additional information to the central nervous system about changes in muscle tension, static position of a joint in a space and endpoint position of joints during active movement.[72] Only a few studies have examined structural age-related changes in joint receptors; none have examined GTO age-related changes. Researchers have reported a decline in the number of joint receptors as subjects increased in age [82,83]. Previous studies have shown that older subjects had decreased dynamic ankle joint position sense, and proprioception decline was highly associated with the eyes closed single leg stance position [84]. Furthermore, older adults with knee osteoarthritis have decreases in the number of joint receptors, which was associated with increased body sway during standing with both eyes open and eyes closed.[85]

The cutaneous mechanoreceptors provide important feedback to the central nervous system about touch, pressure, vibration, and cutaneous tension.[72] Multiple studies have shown that the number of mechanoreceptors decreases with aging.[86,87] Other studies demonstrated that the vibration sensation threshold in the great toe increased by three fold by the age of 90 years,[88] and tactile sensitivity declined with age.[89] Older adults lose vibration perception with age, especially in the lower extremity.[90]

A number of clinical tests of balance that examine how subjects utilize somatosensory information are performed when subjects stand on a foam or moving surface.[91,92] Therefore, in order to understand the contribution of the somatosensory system to the body's postural control in a balanced stance, investigators have examined the somatosensory system under altered surface conditions. They found that body sway increased markedly, indicating that proprioception plays a crucial role in human postural control.[93–95]

One common method to assess the effect of somatosensation on balance is to have older adults stand on a foam surface, which will challenge postural control by reducing the reliability of information from ankle mechanoreceptors.[96] Researchers have demonstrated a decrease in older adults' postural stability when standing on a foam surface that was attributed to the deterioration of input received from ankle cutaneous mechanoreceptors, which affects somatosensory feedback.[96,97] In a different study, researchers reported that the effects of standing on a foam surface are increased when both eyes are closed and a higher reliance is placed on somatosensory information.[98] Moreover, foam decreased the accuracy of somatosensory information from both feet.[99]

Vision:

Vision plays a significant role in maintaining postural stability by providing the nervous system with information about one's position within the surrounding environment.[16] Advancing age is associated with a general decline in visual performance. Structural age-related changes within the visual system include visual field loss, decreased visual acuity, and poor visual contrast sensitivity, which causes an impairment in depth perception and contour.[100] These changes with aging in the visual system alter a wide range of functional skills, including postural control.[101,102]

A number of studies have reported that postural instability significantly increased under conditions in which older adults had their eyes closed.[103,104] It has been demonstrated that the presence of visual information can reduce postural instability by up to 50%.[105] In studies where the authors studied the effects of vision on postural control in the elderly and compared it with young adults, they found that healthy older adults showed increased body sway and center of pressure (COP) displacement in conditions where visual information was altered as compared with healthy young adults.[106,107] Therefore, older adults with visual impairments tend to use hip strategies to maintain balance to maintain postural stability on unstable surfaces.[108]

To understand the visual contribution to postural control during quiet stance in the elderly, researchers assessed body balance under conditions where vision was altered. When standing with eyes closed, elderly people showed greater body sway than when standing with their eyes open.[109] Body sway increases even more when standing on a foam surface with eyes closed, which indicates that vision becomes more important when somatosensory inputs are disrupted.[104,110,111] Body sway increases by about 20–70% when older adults stand with their eyes closed on a level surface.[98,112] Healthy elderly adults show greater increases in body sway in computerized dynamic posturography than in the healthy young group, especially in condition 4 (eyes open and sway-referenced surface) when somatosensory inputs were distorted.[95,104,113]

Vestibular:

The vestibular system contributes to postural stability, and provides information related to head position and movement. The vestibular end organ is located within the inner ear and it consists of the otolith organs (utricle and saccule), which sense linear acceleration (gravity) that provide input about the position of the head during linear translations; and the three semicircular canals (anterior, posterior and horizontal canal), which sense angular acceleration that helps to detect head rotation movements.[114]

The vestibular system makes an important contribution to standing balance. Healthy elderly adults showed greater increases in body sway during computerized dynamic posturography compared to a healthy young group in conditions 5 and 6, where visual and somatosensory inputs were absent or perturbed, as these conditions are difficult for older adults.[95,104,113,115] In cases when visual and somatosensory information is conflicted during conditions 5 and 6, the vestibular system worked as an accurate orientation reference.

Structural changes within the vestibular organs occur with aging. These changes include a progressive reduction in hair cells and nerve fibers within the vestibular system, ,[116–119] neural degeneration,[120] degeneration and reduced number of otoconia,[121–123] and decreased blood supply to the vestibular sensory organs.[124]

Alterations with aging in vestibular function have also been documented. In a study where researchers compared older and younger people, results indicated an age-related decline in vestibular function.[125] This decline manifests in a decrease in the vestibulo-ocular reflex (VOR) gain, especially for higher velocities revealed by rotational chair testing,[125–127] and increases in the VOR phase leads.[113] In a 5-year longitudinal study of vestibular function in subjects older than 70 years, a significant decline in the VOR was observed for both healthy and dizzy older adults by using the rotational chair test.[127] By using the head thrust dynamic visual acuity testing (htDVA), a decline in semicircular canal function has been noted in older adults compared to young individuals.[128] In a different study, where investgators used the dynamic visual acuity (DVA) to test vestibular function, a decline in the DVA started at age 50.[129]

In an epidemiological study of vestibular dysfunction that was conducted using data from the National Health and Nutrition Examination Survey (NHANES), vestibular function was examined in more than 5,000 people aged 40 and older. Subjects were asked to stand on a foam surface with their eyes closed for 30 seconds. About 35% of the participants were unable to maintain their balance, and the risk of falling increased significantly for those who failed to complete the test.[130]

These changes in the vestibular system with aging are likely an important factor in the increased incidence of falls in the elderly; about 73% of older adults who underwent a fall risk assessment displayed decreased vestibular function.[131] A decline in vestibular function can have destructive effects on postural stability.[132] Most falls during the SOT have occurred under conditions where visual and somatosensory inputs were absent or perturbed. [105] Therefore, degenerative changes in the vestibular system may result in difficulty resolving multisensory conflict.[133]

2.3.2 Age-related changes in sensory integration and age-related white and grey matter changes standing balance

2.3.2.1 Changes in Sensory Integration

The central nervous system (CNS) integrates sensory information from the visual, vestibular, and somatosensory receptors to produce an internal representation of the body position in space. Postural control is the result of this multisensory integration; it provides motor commands to the musculoskeletal system to maintain upright stance and reduce postural sway.[134] In case of sensory input conflict, more complicated processing is needed.[135]

The CNS identifies the differences among the sensory inputs and decreases the weight of the unreliable input from sensory receptors while, at the same time, increasing the weighting of inputs from the sensory systems believed to provide more accurate information.[136–138] This process of adapting to the available sensory inputs and changing environmental conditions is referred to as sensory re-weighting.[63,139–141]

To provide a quantitative assessment of sensory integrative ability among the three sensory systems (i.e., vision, vestibular, and somatosensory), in order to maintain postural stability, the Sensory Organization Test (SOT) was implemented using Computerized Dynamic Posturography (CDP).[142–144] Subjects stand under six different conditions that investigate the effect of availability and accuracy of sensory information from their somatosensory and vision systems. The first condition examines how the three sensory systems contribute to postural control. Conditions 2 and 3 examine the effect of absent and inaccurate visual inputs on balance control on a firm surface. In condition 4, subjects rely mainly on visual and vestibular information to maintain balance while somatosensory inputs are disturbed. The last two conditions, 5 and 6, examine the influence of inaccurate somatosensory information and absent or degraded visual feedback on postural control on a moving surface. Healthy adults sway the least in conditions when somatosensory inputs accurately provide information about the body's position in space relative to the support surface, despite the availability and accuracy of visual sensation (Conditions 1, 2, and 3). However, when somatosensory information is no longer accurate as the support surface moves, body sway increases. The greatest amount of body sway was recorded during conditions 5 and 6, in which only the vestibular input was accurate and available to maintain balance control. Generally, healthy subjects are able to maintain balance under all the SOT conditions, indicating the ability of the CNS to adequately weight sensory inputs.[113,142]

Age-related changes in central sensory integration and reweighting have been studied. Studies in which visual and somatosensory inputs were manipulated have suggested that a decline in the ability to compensate for sensory conflicts increase with age and is associated with postural instability.[62,104,145] In conditions when there are conflicting sensory inputs, both younger and older subjects swayed, but older subjects had greater sway and balance losses.[146–148] Therefore, the ability to integrate sensory inputs and the process of sensory reweighting appears to be slowed with normal aging.[135,149,150]

2.3.2.2 Age-related white and gray matter changes

Multiple studies have identified a reduction in both gray and white matter volume in older adults compared to young adults,[151–153] but the decline rate is more accelerated in white matter than gray matter volume.[154] The reduction in gray matter volume in the cerebellum and prefrontal regions was associated with slower gait speeds and poorer semi-tandem balance.[155] The white matter lesions, which can be seen on MRI images as white matter hyperintensities (WMHs), were associated with balance and gait impairment in elderly people;[66,156,157] increased volume in the frontal and periventricular WMHs were associated with balance impairment, and hence, increased the risk of falls;[158] and greater WMHs were related to falls in older adults.[159] In addition, a significant correlation between WMHs and mobility impairment includes decreased gait speed and reduced SPPB scores.[160–166]

2.4 CONTRIBUTION OF LOWER-EXTREMITY MUSCLE STRENGTH TO POSTURAL CONTROL

2.4.1 Aging and changes in lower-extremity muscle strength

In addition to the sensory systems, the motor system is an important contributor to postural stability. Part of the main musculature required for postural control includes the ankle plantar-flexors, knee extensors, and hip abductors. The strength of the knee extensors was found to be an independent predictor of postural sway in older adults when standing on an unstable surface.[102] The plantar-flexors prevent the center of mass from moving anteriorly beyond the base of support, while the ankle dorsiflexors control backward sway. Hip abductors control lateral stability in order to maintain postural stability.[69,167,168]

Lower-extremity weakness has been found to be related to postural instability and a risk factor of falling in older people.[169,170] The inability to produce force in the lower-extremity muscles leads to balance impairment.[171] In addition, researchers found that a reduction in ankle muscle torque was clear in older adults who had the highest balance impairment on the Sensory Organization Test (SOT).[56] Another study showed a significant relationship between balance performance and hip muscle strength in older adults.[172] In intervention studies, the improvement of lower-extremity strength has improved balance control.[173–175] In a different study, where investigators compared lower-extremity muscle strength between “fallers” and “non-fallers,” they found a more significant decrease in muscle strength in “fallers” compared to “non-fallers”.[56,170,176]

The age-related loss in skeletal muscle volume and mass has been well documented; researchers found a decrease in the cross-sectional area (CSA) in skeletal muscle with aging.[177,178] Across the age spectrum from 20 to 80 years, there is about a 30% decline in muscle mass and a decrease in the CSA of about 20%.[178] This age-related loss in muscle mass and function has been referred to as sarcopenia.[179,180] The reduction in muscle mass with aging was found to be a significant contributing factor to the decline in muscle strength.[76,181,182]

The normal aging process leads to muscle mass and strength declines in humans. Investigators who studied muscle strength across different age groups indicated that muscle strength decreases in healthy men and women by 20–40% after the seventh decade.[183–186] Other researchers reported that after the fifth decade, a loss of muscle strength would increase by more than 15% per decade.[76,187–191]

2.5 ASSESSMENT OF BALANCE AND STRENGTH IN COMMUNITY-DWELLING OLDER ADULTS

2.5.1 Postural Control and Balance Assessment

Postural control can be described as the ability to control the position of the body in space in order to achieve an upright, stable stance. To achieve this goal, the body's center of gravity (COG), defined as the vertical projection of the center of mass (COM), should be maintained within the base of support (BOS).[192,193]

Movements of the center of mass (COM), center of pressure (COP), and limits of stability (LOS), are used to quantify postural sway and define balance. The COM is a passive variable that represents the net location of body mass; the vertical projection of COM onto the ground is called the COG. The COP represents the center of distribution of the total force of body weight over the surface of the area in contact with the ground; in other words, it is the location of the vertical ground reaction force vector.[69] The boundaries of movement within which the body can maintain balance is called the LOS.[193]

Several methods have been developed to assess balance in older adults. A number of task-based balance tests have shown to have a good reliability such as the Berg Balance Scale (BBS),[194] and the Tinetti gait and balance assessment.[195] However, the results obtained from task-based tests may be susceptible to examiner's bias, suffer from floor and ceiling effects, cover limited aspect of balance, and usually lack of the sensitivity to detect small changes in balance.[28–30]³⁰ Over the last two decades, quantitative assessments of postural sway during standing (such as computerized dynamic posturography (CDP), and force plates) have been used to assess balance and identify postural instability in older adults.[31] Although CDP has been a well-accepted measure of postural stability, due to its cost, required space, lack of portability, and the required training associated with its software, it has resulted in limited clinical usage. In addition, the ability to use CDP with people who live in community settings has been limited due to the high cost and immobility. Another drawback for using CDP is using the COP measurement generated from the device. The assumption behind relating COP to the measure of postural stability is that displacement of the COP is assumed to be proportional to the acceleration of the center of mass, i.e. the body moves as an inverted pendulum at the ankle. However, this is not the case when different balance strategies are used especially during more challenging balance conditions in older adults.[31,196]

Recent technological advancements have provided an alternative quantitative method to assess balance that is inexpensive and portable, i.e. body-worn accelerometers. Accelerometers are used to quantify postural sway in both anteroposterior (AP) and mediolateral (ML) directions during standing. Accelerometers have been shown to have the ability to discriminate between test conditions that require different levels of postural control, between fallers and non-fallers, and young versus older adults.[34–37] Assessing postural stability by using accelerometers has been applied to different populations including: people with Parkinson disease,[39] multiple sclerosis,[40] and with community-dwelling older adults.[41] In addition to the cost efficiency and greater mobility, the main advantage of using accelerometers over a force plate is that it can quantify the COM movement by placing the accelerometer around the waist. Since the vertical projection of the COM must be kept within the base of support in order to maintain balance, the COM represents the variable that must be controlled.

To bridge the gap between expensive and immobile force platforms and task-based measures, and by taking the advantage of technological advancements, accelerometers provide a portable and inexpensive way to quantify postural stability out of a lab setting and with understudied populations such as people living in independent living facilities, who may have difficulty getting transportation to research labs, resulting in limited access to this population.[49] However, these accelerometer reliability studies were limited to clinical and lab settings, and had not been investigated outside in the community. Recently, a study by Saunders et al.,[38] was published after we had started this project, in which they found good to excellent test-retest reliability for using a tri-axial accelerometer to quantify postural sway in people who live in independent living facilities. Although the Saunders et al. study shares some of the same standing balance conditions, our study included more standing balance conditions, used a different foam surface, and examined normalized path length as balance parameter.

2.5.2 Lower Extremity Muscle Strength Assessment

The current gold standard method to measure lower extremity muscle strength is using computerized isokinetic dynamometry.[43] The high financial and time cost, space requirements, and non-portability are drawbacks that limit the application of computerized isokinetic dynamometry in independent living facilities. Another method to assess strength in clinical settings is manual muscle testing. Although it is the most frequently used technique to quantify muscle strength in clinics and is easy to use, it lacks sensitivity and responsiveness, is susceptible to examiner's error, and is subject to a ceiling effect.[44,45] Handheld dynamometers have been used in different settings to objectively quantify muscle strength. Even though handheld dynamometry has good reliability in different populations, it has some important limitations, such as difficulty in stabilizing the subject, and the reading is influenced by the strength of the examiner especially for larger muscles.[46,47] The concept of using a simple strain-gauge uniaxial load cell device has been proposed before but it has not been used with people who live in community settings.[48] The uniaxial load cell device provides an easy and reliable way to overcome the aforementioned drawbacks and quantify muscle strength in different settings outside the clinic.

2.6 PSYCHOMETRICS AND THE MINIMAL CLINICALLY IMPORTANT DIFFERENCE OF BALANCE AND STRENGTH MEASUREMENTS IN INDEPENDENT LIVING OLDER ADULTS

2.6.1 Investigating validity and reliability of balance and strength measurements

Two essential elements of psychometric properties are validity and reliability. Reliability is a pre-requisite to validity; in other words, a measure cannot be valid unless it is reliable. In order for an assessment tool to be confidently recommended in research or clinical practice, it should be adequately reliable and valid.[197] The concept of reliability refers to as the consistency of a measurement over time. Reliability yields the same results when a measurement tool is administered multiple times, without change to the construct being measured.[197] Measures of balance and strength should be reliable if intended to be used in research or clinical practice to examine the effect of an ongoing intervention program.

Estimating reliability is aimed to determine the amount of the variability in test scores that is due to errors in measurement and the amount of the inherent variability in true scores.[198] All measurements, including balance and muscle strength tests, consist of an error component when it is being tested on two different occasions.[197] This means that the measured value is the product of the true value plus error. Therefore, the reliability index is an estimate of a measurement that is attributable to error and the part that represents the true value.[197]

Reliability is variously estimated in different forms. Test–retest reliability is a common way to examine the consistency of a measurement, to provide clinicians with assurance that the results obtained by an instrument are stable over time.[197] Test–retest reliability can be measured using relative and absolute reliability indexes. The intraclass correlation coefficient (ICC) is commonly used to estimate relative reliability, and it is defined as the ratio of between-subject variability to the total variability.[199] The ICC index ranges from 0 to 1; values that are closer to 1 represent a higher reliability. Values of the ICC from 0.40 to 0.75 indicate fair to good, and values greater than 0.75 represent excellent reliability while values less than 0.40 indicate poor reliability.[200]

Reliability is a crucial aspect of responsiveness. It is difficult to find a true change in instruments with poor reliability because the noise caused by the measurement error might mask any real change that has occurred. A study to establish the psychometric properties of balance accelerometry and load-cell strength testing is imperative in order to apply these technologies in studies with independent living older adults. Published studies that have examined the reliability of using an accelerometer to quantify RMS sway, in the AP and ML directions, reported ICCs ranging from 0.16-0.71 for standing on a firm surface with eyes open.[37,201–203] Previous studies have also documented ICCs for RMS sway ranging from 0.45-0.52 for standing on a firm surface with eyes closed [37,201] Other studies [42,204] reported the reliability for NPL sway measures using a similar accelerometer during standing on a foam surface with eyes open and eyes closed in the AP direction with ICCs of 0.74, and 0.82, respectively.

Previous studies showed a significant correlation between postural sway and clinical-based measures such as the SPPB[205,206] and between postural sway and the Activities-specific Balance Confidence.[207] However, a weak correlation was found between the 6MWT and postural sway measures. A strong correlation has been shown between lower extremity strength measurements using HHD and repeated chair stands time in studies where they combined all lower extremity strength tests together.[208] The relationship of muscle strength to gait performance is modest at best.[54]

2.6.2 The Minimal Clinically Important Difference (MCID) of Balance and Strength Measurements

An important component of psychometrics is to estimate the minimum clinically important difference. The MCID is defined as the smallest change perceived as important by patients.[209] Identifying a MCID for balance and strength measurements using both accelerometer and load cell will help clinicians and researchers to recognize a real and important change in patients' performance. Postural stability and muscle strength instruments need to be responsive enough to detect clinically important changes that result from exercise interventions so that they can be used to track improvement over time.

There are two different approaches that can be used to determine the smallest amount of change on measurement that is likely to be meaningful or important, including distribution-based and anchor–based approaches. The first approach is the distribution-based approach, which is based on the statistical characteristics of the obtained sample. There are different metrics within the distribution-based approach, such as the standard error of measurement, standard deviation, effect size, and minimal detectable change. The standard error of measurement (SEM) is defined as the variability between an individual's observed score and the true score.[210] A change smaller than the SEM is likely due to measurement error rather than a true change in the performance. The second distribution-based method is to use effect size (ES). The ES is a standardized measure of change obtained by dividing the difference in scores between baseline to follow-up by the standard deviation of baseline values.[211] The value of effect size represents the number of SDs by which the individual's score change from baseline to intervention. The effect size estimate is based on the baseline standard deviation of each outcome measurement; a small change was computed as $0.2 \times SD$, and a moderate change as $0.5\times SD$.

The second approach is the anchor-based approach. Anchor-based approaches compare the change in a patient-reported outcome to an external criterion or anchor.[212] The global rating of change is commonly used as an external reference or anchor that is based on subjects' perspective if change has been experienced or not. Consequently, these data will help establish the minimal clinically important difference (MCID), which can be used clinically as a cut-off score to determine who has improved after a specific intervention. One method within the anchor-based approaches that was used in this study is "between-patients" score change,[211] which compares the difference in mean change in balance between groups with different responses to a global rating of change scale.

There is no consensus on the best method to determine the MCID, and it has been recommended to estimate the MCID based on multiple approaches to obtain a range of values, as we did in the present study.[211] To the best of our knowledge there are no published studies that estimated the MCID using accelerometers and a uniaxial load cell device.

2.7 EFFECT OF EXERCISE INTERVENTIONS ON MOBILITY AND BALANCE

A wide range of exercise interventions have been developed and intended to improve walking ability and decrease mobility limitations in older adults. Most of the exercise interventions that have tried to enhance walking and mobility have been a multifactorial approach concentrating on the impairment of the involved systems; recently, more functional-based exercises and training have emerged. [213–216]

Multifactorial approach intervention programs have included strengthening, flexibility, and endurance components.[213–215] This approach aims to resolve the underlying impairment (e.g., muscle weakness, restricted ROM). The focus of this approach is to have an impact on the impairment that has the greatest effect on balance and mobility in community-dwelling older adults.

The optimal goal of the impairment-based approach is to promote capacities of muscle strength, range of motion, and endurance. For instance, during resistance training interventions, subjects exercise their muscle against an external force; this resistance force is gradually increased over the course of training.[217] The magnitude of effect from such training is greater for muscle strength outcomes compared with balance and mobility outcomes.[218] The impairment based exercise approaches usually focus on enhancing the physiological capacity of the body systems that are involved in gait, but the lack of task-specific exercise makes the use of this improvement in physiological capacity of the body systems limited.[219] Various studies using the multifactorial impairment approach have shown no significant effect on walking or balance measures.[175,213,214,220,221] Other investigators have demonstrated slight improvements.[24,25,215,222,223]

In order to overcome the aforementioned limitations, a task-oriented motor learning group-based exercise has been developed called *On the Move* (OTM), which aims to improve walking and promote independence in older adults by incorporate timing and coordination components. Preliminary data showed a significant improvement in walking and mobility measures in people who received the OTM exercise program, whereas people who received the standard strength and endurance exercises demonstrated consistent worsening in walking ability.[27]

The concept of task-oriented training has been used mostly in neurological rehabilitation. Growing evidence suggests that task-oriented ambulation exercises have improved walking function in people with neurologic deficits.[26,224] The underlying mechanisms of the task-oriented approach are different than those in an impairment-based exercise program. The task-specific motor learning program is intended to enhance older adults' motor plan selection for walking. More precisely, the task-oriented approach helps in improving walking skill through strengthening components, neuromuscular control, and providing feedback to enhance performance.[219] Moreover, task-oriented based exercise helps in achieving improvement in walking by implementing motor-skill-based principles that include: a defined movement goal, movement to gain knowledge of postures and muscle, practice to reduce errors in movement and build up motor plans, and a challenge to select the appropriate motor plan.[27] The task-oriented program aims to promote motor learning strategies, thus challenging the central nervous system to adapt to the task demand and the environmental context, and to learn the pattern of the movement in order to improve walking ability.[219] Finally, the task-oriented exercise helps utilize the improved physiological capacities to help in selecting the proper motor plan in order to meet the task demand.[193] As an example of this type of training approach, Tsaih et al.[225] has examined the effect of low intensity task-oriented stepping and walking program on walking and balance in older adults. Although, the duration of the program was short, which lasted for only 4 weeks, an improvement in walking and standing balance outcomes was reported.

2.8 SUMMARY

Given the association between walking difficulty and risk of falling and risk of dependency in older adult,[226,227] the new task-based walking exercise program (OTM) aims to improve walking and promote independence in older adults by incorporating timing and coordination components. Impairments in balance, gait and lower extremity strength are strong factors associated with decreases in mobility and dependence in activities of daily living among older adults. Although the OTM exercise program was originally designed to improve the skill of walking, it has many activities that include balance and strength components. It has not been studied if the OTM exercise program has an effect on balance function and lower extremity strength.

Laboratory-based balance and strength tests are usually expensive and not portable, so the access to these tests is limited for large group of people such as people who live in community settings. Recent technology advancements have provided us with technology-based measures that are inexpensive and portable to assess balance and muscle strength. To our knowledge no study has applied these technological advancements in in community settings. So, there is a need to validate and test the reliability of the upright balance and lower extremity muscle strength measurements using inexpensive and portable devices that can be used in independent living facilities. Therefore, the main purpose of the study is to assess the test–retest reliability and validity of standing balance and lower extremity muscle strength measurements. The secondary purpose is to determine if there is an effect of exercise interventions on standing balance performance and lower extremity muscle strength in community dwelling residents.

3.0 RESEARCH DESIGN AND METHODS

3.1 STUDY DESIGN

This study was an ancillary study to an ongoing clinical trial called "*On the Move*". The ancillary study was designed to determine the effects of two different interventions on standing balance and lower-extremity strength in community dwelling residents. The parent study involved two intervention groups, including the "On the Move" (OTM) exercise group and a standard exercise group, and two wait list control groups. As shown in **Figure 3.1**, sites were randomly allocated to either the OTM exercise group or standard exercise group and then after the first baseline testing, subjects in both intervention arms were again randomly assigned to either the wait list control group or exercise group. For each intervention, half of the subjects started the exercise intervention immediately, and the other half had a 12-week wait period before starting the intervention. Exercise leaders who had training and experience in administering exercise programs, such as physical therapists or physical therapist assistants, delivered the first 12 weeks of the OTM and standard exercise interventions. In the original study design, a staff activity employee was to be trained to deliver the exercise program for the wait list exercise groups during the second 12-week period. The subjects in the wait list group were used as a control group. The outcome measurements were taken before the subjects started and after they completed the intervention.

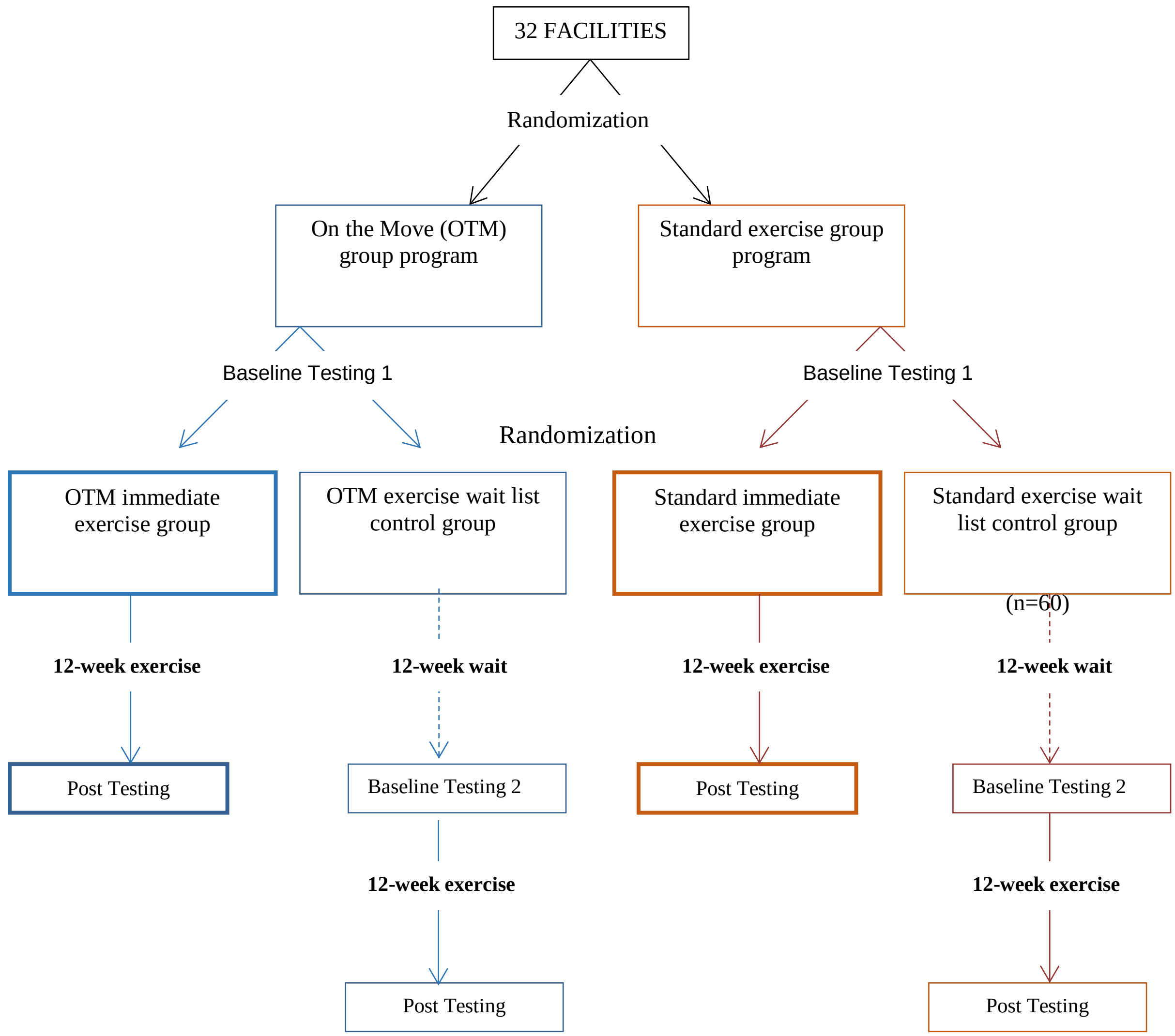

Figure 3.1: Study design to compare the effects of the *"On the Move"* versus the standard exercise program in older adults.

3.2 INCLUSION/EXCLUSION CRITERIA

Subjects were included in this study if they were eligible for the parent OTM study. Subjects were required to meet all of the following inclusion criteria in order to be included in the parent study: (1) 65 years of age or older; (2) a resident of a University of Pittsburgh Medical Center (UPMC) independent living facility (ILF), senior housing site, and senior community centers; (3) ability to ambulate independently within the household with or without a straight cane; and (4) gait speed greater than or equal to 0.60 m/s.

Subjects were excluded if they had one or more of the following exclusion criteria: (1) Non-English speaking; (2) impaired cognition, which is defined as the inability to follow two-step commands or understand the informed consent process; (3) plans to leave the area for an extended period of time over the next four months; (4) a progressive neuromuscular disorder such as Parkinson disease or multiple sclerosis; (5) any acute illness or medical condition that was not stable; and (6) inappropriate response to the 6 minute walk test.

3.3 SETTING AND PARTICIPANTS

A convenience sample of 131 people were recruited from 18 different sites (7 independent living facilities, 3 senior community centers, and 8 high rises) within the University of Pittsburgh Medical Center senior communities. The investigators of the parent OTM study informed the subjects about the current study. If the subject expressed his or her interest, the principal investigator of the current study would then meet the subject and explain the study to him or her, including the overall purpose of the study, the study procedures, number of visits, and the potential benefits and risks of participating in the study. If the subject was willing to proceed, the principal investigator obtained informed consent, as approved by the University of Pittsburgh Institutional Review Board (IRB).

3.4 INTERVENTION PROGRAMS

3.4.1 On the Move exercise program

The *On the Move (OTM)* exercise program is 50 minutes exercise program that aims to promote skill in walking acquisition based on principles of motor learning. The OTM program consists of 5 components: warm-up exercises (5 minutes), stepping patterns (10-20 minutes), walking patterns (10-20 minutes), strengthening exercises (10 minutes), and cool-down exercises (5 minutes). The warm-up includes basic weight-shifting and stepping exercises to prepare the musculoskeletal and cardiopulmonary systems to exercise. The walking patterns consist of walking in a variety of pre-determined patterns using cones to create different walking patterns. The stepping patterns include an extensive progression of stepping sequences. The stepping and walking patterns are goal-oriented which are designed to promote the appropriate timing and coordination of stepping during walking by enhancing proper weight-shift during stepping and appropriate coordination of the legs and trunk during walking. These exercises were progressed by altering speed, amplitude, or accuracy of performance. The strengthening exercises included a series of lower extremity exercises that aimed to increase muscular strength, and were conducted in both sitting and standing, such as seated marching, seated hip abduction, and repeated chair stands. Finally, the cool-down contained gentle range of motion exercises and stretches for the lower extremities and trunk to return the body to the resting state. The majority of the program was conducted in standing (40 minutes) with only a small portion conducted in sitting (10 minutes). A specific music playlist was designed to be played during OTM classes. The exercise sessions were twice weekly for 12 weeks and were delivered by exercise leaders and activity staff personnel.

3.4.2 Standard exercise program

The standard group exercise program is based on exercise programs that were currently being conducted at the facilities (i.e. standard of care). The operationally defined program contains warm-up exercises (10 minutes), cardiovascular exercises (20 minutes), strengthening exercises (15-20 minutes) and cool-down exercises (10 minutes). The warm-up and cool-down contained gentle range of motion exercises and stretches for the lower extremities and trunk. The cardiovascular exercises consisted of exercises for the heart, such as arm and leg movements causing the heart rate to go up. The strengthening exercises were conducted in both sitting and supported standing position included seated marching, seated hip abduction, and repeated chair stands that targeted the lower extremity muscles. The majority of the program was conducted in sitting. Similar to the OTM program, a specific music playlist was designed to be played during standard exercise classes. The exercise sessions were twice weekly for 12 weeks and were delivered by exercise leaders and activity staff personnel.

3.4.3 Wait list control group

The reason of adding a wait list group, in the original study, was to examine the sustainability of the program. Therefore, exercises were delivered by an exercise leader employed by the research study for the first 12 weeks of both interventions. Although staff activity personnel employed by the facilities were intended to deliver the interventions for the wait list group, this did not happen at all facilities.

3.4.4 Test–retest reliability group

A subsample of approximately 38 subjects from the entire population returned for a test–retest reliability assessment one week after one of the experimental study visits. The visit included both balance and strength measurements. The visit number and experimental study group from which they were selected was not controlled.

3.5 EQUIPMENT

3.5.1 Balance Accelerometry (BA)

The accelerometer was developed as a part of the National Institutes of Health (NIH) Toolbox project as a balance measurement.[42] The BA system consists of a dual axis accelerometer (ADXL213AE, with range of ±1.2 g and resolution of 1mg; Analog Devices, Inc., Norwood, MA) oriented to record mediolateral and anteroposterior acceleration of the body. The acceleration is transmitted via a Bluetooth transmitter to a laptop computer at 50 Hz and with 16-bit accuracy. The system was affixed to subjects' backs at the level of the iliac crest using Velcro and a gait belt (**Figure 3.2**). A custom written Labview program was used to acquire the data. The foam surface that was used in the testing consisted of an AIREX® Balance Pad (Alcan Airex AG, Switzerland), and the foam pad thickness was 6 cm.

Figure 3.2: An accelerometer placed on back of subject, using Labview software to acquire balance data

3.5.2 Uni-axial load cell device

A uni-axial load cell (Measurement Specialties XTC Series) was used to measure lower extremity strength. The load cell has a maximum capacity of 2225 N. The load cell was connected to an amplifier that displayed the instantaneous and maximum force exerted on the load cell. The load cell is arranged in series with straps (two cuffs) that fit around the limb on one end and a stable object on the other end (Figure 3.3)

Figure 3.3: A load cell transducer and amplifier on the left. On the right the load cell is attached to subject's legs to measure seated hip abductor muscle strength.

3.6 EXPERIMENTAL PROCEDURE

3.6.1 Balance accelerometry test

The BA protocol was composed of six different conditions that were based on two tests. The first test was the modified Clinical Test of Sensory Interaction in Balance (mCTSIB),[228] which was designed to examine the utilization of the three important sensory systems (i.e. vision, somatosensory, and vestibular) for postural stability. The second test was the instrumented Short Physical Performance Battery (SPPB),[229] which measures different aspects of functional mobility, and the ability to stand with a narrow base of support. The order of testing was presented to each subject, from easier to more challenging conditions, as follows: (1) Standing with feet together on a firm surface with eyes open (Firm-EO); (2) standing with feet together on a firm surface with eyes closed (Firm-EC); (3) standing with feet together on a foam surface with eyes open (FOAM-EO); (4) standing with feet together on a foam surface with eyes closed

(FOAM-EC); (5) standing with a semi-tandem (one foot halfway in front of the other) stance on a firm surface with eyes open; and (6) standing with a tandem stance on a firm surface with eyes open. For the semi-tandem and tandem stance conditions, the subjects placed their feet according to their preference.[230] During these conditions, subjects stood 0.5-meters from the wall with their shoes on and their arms were crossed in front of their chests. In order to standardize shoe-wear, subjects were asked to wear their customary walking shoes (i.e. no high heels, no sandals) for the testing. Each condition was performed for 30 seconds. The subjects were allowed to perform each condition two times. If the subjects failed to perform both trials of a condition, they would continue onto the next condition, and the investigator would document that the subjects weren't able to complete the task.

3.6.2 Lower-extremity strength testing

Strength measurements included three maximum voluntary isometric contractions (MVIC) for three different muscle groups. All of the testing was done in sitting position. Testing positions have been adopted from studies that have used isokinetic and isometric dynamometers; details about the device positions for each muscle group are summarized in **Table 3.1**. To standardize which leg was tested, the dominant foot was determined by asking the subjects about the foot that they would use to kick a ball for the knee extension and ankle plantarflexion.[231] Hip abductor strength was necessarily tested bilaterally. The tone and words of encouragement used by the examiner were standardized. During each trial, the subject increased force up to a maximum over the course of five seconds. Thirty seconds of rest was provided between trials.

The peak value was recorded from the amplifier. The average of the three trials was used in the data analysis. All of the measurements were taken by a physical therapist.

Table 3.1: Testing positions for strength measurements

Isometric Action	**Testing Device Position**
Hip abduction	One cuff was placed proximal to the right knee and the other cuff proximal to the left knee. In the sitting position, starting with knees together, the subject was asked to move both knees apart gradually until he/she reached the maximum force over the course of five seconds.
Knee extension	One cuff of the device was placed at the bottom of chair leg and the other cuff around the subject's dominant leg just above the ankle. In the sitting position, the subject was asked to extend the knee gradually until he/she reached the maximum force over the course of five seconds.
Ankle plantarflexion	With the knee of the dominant leg extended in sitting, one cuff was placed at the top of the dominant foot right below the toes and the examiner held a bar with the other cuff attached to it. Subjects were asked to plantarflex his/her ankle gradually until he/she reached the maximum force over the course of five seconds.

3.7 OUTCOMES

The main outcome measures are the postural sway measured by the accelerometer during the mCTSIB and SPPB tests, and the lower extremity strength measurements. Both were measured at baseline and after 12 weeks for all subjects, and after 24 weeks for subjects who were in the wait list groups. Secondary outcome measures, were obtained from the "On the Move" study, included the Six Minute Walk Test (6MWT), gait speed, Figure of 8 Walk Test (F8WT)**,** the repeated chair stands test, Gait Efficacy Scale (GES), and the Short Physical Performance Battery (SPPB**)**.

Six-minute walk test (6MWT):

The 6MWT is well-validated measure of walking capacity. It was used to assess walking endurance by measuring the maximum distance a person can walk (in meters) in six minutes, including time for rest as needed.[232] The 6MWT is reported to have excellent test–retest reliability (Pearson r = 0.95) in older adults.[233] A change in walking distance of 20 m has been proposed as a small meaningful change, and 50 m as a substantial meaningful change.[234] Better performance is indicated by greater distance covered during six minutes.

Gait speed:

Subjects were asked to walk at their usual, self-selected speed on instrumented walkway. The instrumented walkway was 2ft wide and 14ft long and has pressure sensors embedded within its length to detect and capture data as the individual walked on the walkway. After 2 practice trials, participants completed 6 trials that were used for data collection. Gait speed was averaged over the 6 trials. The test–retest reliability of gait speed measured using an instrumented walkway was

ICC=0.98 in older adults.[235] A change of 0.10 m/s in gait speed has been indicated as substantial meaningful change and 0.05 for small meaningful change.[234]

Figure-of-8 walk test (F8WT):

The F8WT was used to measure motor skill in walking. Participants walked a figure of eight pattern at their self-selected speed around two cones placed 1.5 meter apart. The time and number of steps to complete the F8WT was recorded. The F8WT has established excellent psychometric properties in older adults, inter-rater reliability (ICC=0.90 for time and ICC=0.92 for number of steps) and validity by comparison to measures of gait, motor control and function.[236] A longer time and higher number of steps indicates worse skill in walking.

Repeated Chair Stands test:

As part of the Short Physical Performance Battery, participants were asked to perform five consecutive sit to stands as quickly as possible with their arms crossed in front of their chest. This test was used to measure lower extremity strength. The time required to complete the task was recorded.[229]

Gait Efficacy Scale:

The Gait Efficacy Scale is a self-reported 10-item scale that addresses older adults' perception of their level of confidence in walking during challenging circumstances, including walking over different surfaces, curbs, or stairs. Item scores on a 10-point Likert scale with 1 denoting no confidence and 10 for complete confidence, with a possible total score of 10–100.[237]

***Short Physical Performance Battery (SPPB)**:*

The SPPB was developed as a measure of physical performance for a longitudinal study of aging conducted by the National Institutes on Aging.[229] The SPPB measures three aspects of functional mobility: the time to perform five consecutive transfers from sitting to standing (chair stands), time to ambulate on level surfaces for 4 meters, and the ability to stand with decreasing medial-lateral base of support. Scores from 0 to 4 are assigned to each of the tasks based on quartile scores of the timed chair stands and ambulation, and degree of difficulty of the standing balance test. A summary performance score is equal to the sum of the three sub-scores. Lower scores on the SPPB are associated with elevated risk of death,[229] nursing home admission, incident self-reported disability in ADLs and mobility. The duration of testing is 15 minutes. The test-retest reliability of the SPPB over 4 to 7 days ranged from 0.83 to 0.89 in older adults aged 65 to 74,[238] and 0.72 in older adults with mean age of 74 over two week period.[239]

Anchor-based measures:

The anchor-based measure for balance accelerometry was obtained by a change in the Global Rating of State (GRS) in balance scale. Subjects were asked at the beginning of the exercise intervention and at the end to evaluate their balance. The question was stated as, “Would you say your balance in general is excellent, very good, good, fair, or poor?” The response was made on 5-point Likert scale as follows; 1 = excellent; 2 = very good; 3 = good; 4 = fair; and 5 = poor. The difference between responses at the beginning and at the end was calculated. A small decline was defined as a decrease by one point (-1), small improvement as an increase by one point (1), substantial improvement as an increase by 2 or 3 points, and substantial decline as decrease by 2 or 3 points. The lack of an anchor measure for strength prevented us from computing the MCID for the strength measures using an anchor-based approach.

3.8 DATA ANALYSIS

The acceleration data were visually inspected and the abrupt spike-like noise that was caused by sudden movement of the accelerometer was removed. The first and last five seconds of the recording were not included in the analysis in order to eliminate transient effects.[240] Using a custom written Matlab program, the acceleration data were lowpass filtered using a 4th order Butterworth filter with a cutoff frequency of 2 Hz. The cutoff frequency calculation was based on the Nyquist sampling theorem, which states that sampling frequency should be at a frequency greater than twice as high as the highest frequency contained in the signal.[241] A cutoff frequency of 2 Hz is sufficient to capture all the sway signals, since postural sway during quiet standing is typically restricted to low frequencies (<1 Hz).[242]

The Root Mean Square (RMS) and the Normalized Path Length (NPL) for both directions, the anteroposterior acceleration (AP) and mediolateral acceleration (ML) were calculated; a higher value indicates more sway. The RMS and NPL were calculated as follows:

$$RMS = \sqrt{\frac{\left(\sum_{j=1}^{N-1} p_j\right)^2}{N}} \quad \text{mG} \quad (1)$$

$$NPL = \frac{1}{t}\sum_{j=1}^{N-1} \left|p_{j+1} - p_j\right| \quad \text{mG/s} \quad (2)$$

where t is the time duration, N is the number of time samples, and p_j is the acceleration data at time sample j. The mG stands for milli-Gravitational acceleration, where 1 mG = 0.0098 m/s^2 and mG/s is the milli-Gravitational acceleration divided by the time duration in s.

3.9 STATISTICAL ANALYSIS

Data were analyzed using SPSS version 22.0 (IBM, Armonk, NY). The demographic characteristics of the subjects were compared between groups at baseline using one-way ANOVA for the continuous variables and Chi-squared for categorical variables. Any variables found to be significantly different at baseline were accounted for by controlling for any covariates in the main analyses. The statistical analysis will use the change from baseline with adjustment for the baseline. The magnitude of change in values for all of the outcome measures will be computed as the difference between baseline 1 (BL-1) and post-intervention, and between baseline 2 (BL-2) and post-intervention.

3.9.1 Statistical analysis for specific aims

Aim 1:

To investigate the psychometric properties (test-retest reliability, convergent validity, and minimal clinically important difference) of balance accelerometry and lower extremity strength measurements assessed one week apart in independent living older adults.

Test–retest reliability one week apart will be estimated for both balance accelerometry measurements and lower extremity muscle strength. Intraclass correlation coefficient (ICC) (model 3.1) and 95% confidence intervals (95% CI) will be calculated to examine the relative reliability. The ICC is defined as the ratio of between-subject variability to the total variability with values ranging from 0-1. Values that are closer to 1 represent a higher reliability. Values of the ICC from 0.40 to 0.75 indicate fair to good, and values greater than 0.75 represent excellent reliability while values less than 0.40 indicate poor reliability.[200] The SEM will be calculated using the sample standard deviation (SD) and the ICC as follows: SEM = SD $\sqrt{(1 - \text{ICC})}$. [197]

In order to examine the convergent validity of balance accelerometry and lower extremity strength measurements in independent living older adults, the BA and strength measurements were correlated with different mobility measurements such as the Six-Minute Walk Test (6MWT), gait speed, Figure-of-8 Walk test (F8WT), Short Physical Performance Battery (SPPB), Gait Efficacy Scale (GES), and repeated chair stands test. Validity of the measurements was examined cross-sectionally at the initial baseline assessment (BL-1).

We tested the hypothesis that at the initial baseline, participants who had greater lower extremity strength and better balance performance will show a greater gait speed and SPPB lesser time to complete F8WT and repeated chair stands test, and greater walking confidence, and walking distance indicated by the 6MWT.

In order to examine the validity, assumptions of normality and linearity will be tested using the Shapiro-Wilks test and scatter plot visualization. If the assumptions are met, the Pearson correlation coefficient will be used to examine the relationship between postural sway and muscle strength measurements with the various mobility measurements: the 6MWT, gait speed, F8WT, SPPB, GES and repeated chair stands test. If the assumptions are not met, Spearman's rank correlation coefficient will be used to examine the relationship.

In order to estimate the minimal clinically important difference (MCID) for balance accelerometry and lower extremity strength measurements, a range of anchor-based and distribution-based methods will be used. Distribution-based measures of the minimal clinically important difference include the effect size and SEM for both balance and muscle strength measurements. The effect size (ES) estimate was based on the standard deviation of each outcome measurement for all subjects (n=131); a small ES was computed as 0.2 × SD, and a substantial ES was computed as 0.5 × SD.[211] The SEM was calculated using the standard deviation (SD) and the ICC as follows: (SEM = SD √ (1 – ICC)). [211] The SEM was calculated for both the reliability sample (n=38) and the whole sample (n=131).

A linear mixed model using the SAS MIXED procedure was used to compare the difference in mean change in postural acceleration measures over time, with the change in GRS over time. Subjects were classified into three groups based on having no change (n=66), a small decline (n=30), or small improvement (n=28) in GRS score. Subjects with missing values were excluded from the analysis. Subject was included in the model as a random effect.

Aim 2:

Primary: To evaluate the effect of the "On The Move" exercise program on standing balance performance and lower extremity strength in knee extension, hip abduction, and ankle plantarflexion in independent living older adults. Performance will be compared to a standard exercise program, and also to a wait list control group.

Secondary: To examine the effect of the standard exercise program on standing balance performance and lower extremity strength in knee extension, hip abduction, and ankle plantarflexion in comparison with wait list control group.

Primary hypotheses:

Hypothesis 2.1: **OTM-IL vs. STD-IL**

There will be a significant difference in the magnitude of change in balance performance (improvement), but not in the muscle strength, from the baseline assessment (BL-1) to the 12-week post-intervention assessment, between the OTM immediate (I) exercise group conducted by a study leader (L) and the standard (STD) immediate exercise group conducted by a study leader.

OTM-IL: BL-1 12-week OTM exercise program Post-intervention

STD-IL: BL-1 12-week standard exercise program Post-intervention

Hypothesis 2.2: **OTM-IL vs. All Wait list controls**

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the OTM immediate exercise group compared to the combined wait list control groups.

OTM-IL: BL-1 12-week OTM exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

Secondary hypotheses:

Hypothesis 2.3: STD-IL vs. All Wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by an exercise leader, compared to wait list control group.

STD-IL: BL-1 12-week standard exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

Hypothesis 2.4: STD-IL vs. STD-WS

There will be a significant difference in the magnitude of change in balance performance and muscle strength from the baseline assessment to the 12-week post-intervention assessment, between the standard exercise group when delivered by an exercise leader and the standard exercise group when delivered by staff (S) activity personnel, after being on the wait list (W).

STD-IL: BL-1 12-week standard exercise program Post-intervention

STD-WS: BL-2 12-week standard exercise program Post-intervention

Hypothesis 2.5: STD-WS vs. All wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by staff activity personnel, compared to wait list control group. For this comparison, there were some subjects who participated in both groups, and that was accounted for in the statistical analysis.

STD-WS: BL-2 12-week standard exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

A linear mixed model (PROC MIXED) was used to examine the previous hypotheses for balance and strength performance across the exercise groups with the change across time points in each outcome as the dependent variable; treatment group as a fixed effect; sites and subjects as random effects; and pre-intervention score, and any other demographic variables found to be different at baseline between groups, as covariates. Then several ESTIMATE statements in the PROC MIXED procedure were constructed in order to examine the five hypotheses. A significance level of α=0.05 was used for all analyses.

3.10 POWER ANALYSIS

A total of 120 subjects were expected to participate in the study, with 30 subjects per intervention group, and 60 subjects in the wait list control group. Using a 20% attrition estimate, these samples were reduced to 24 in the intervention groups, and 48 in the wait list control group. A power analysis was performed based on standard deviations that were obtained from a previous study of strength and balance performance in residents of long term care facilities, as shown in Tables 3.2, 3.3 and 3.4. The standard deviations for some of the important outcome variables were used in order to compute the difference between two groups and the pre- to post-intervention change that can be detected with the sample size estimates and 80% power, with a significance level of 5%. For instance, for Hypothesis 2.1 (Tables 3.2 and 3.3), using an expected sample size of 24 subjects in each group (OTM-IL vs. STD-IL), we will be able to detect a difference of 9.6 kg between groups for the ankle plantarflexion strength, and to detect a difference of 6 mG between groups for standing on foam surface with eyes open in the AP direction, (effect size Cohen's d=0.82). Similarly, for Hypothesis 2.2 (Table 3.4), using an estimated sample size of 48 subjects in the wait list control group, we will be able to detect change of 4.8 kg for pre-to post intervention change for the ankle plantarflexion strength, and to detect a difference of 3 mG for pre-to post intervention change, for standing on foam surface with eyes open in the AP direction (effect size Cohen's d =0.41).

Table 3.2: List of standard deviations and difference sizes from different balance and strength variables between the two intervention groups

Variables	SD- cross-sectional study	Effect Size	Difference Size
Average Knee Extension (Kg)	7.7	0.82	6.32
Average Hip Abduction (Kg)	7.6	0.82	6.24
Average Ankle PF (Kg)	11.7	0.82	9.61
Level EC APRMS	8.6	0.82	7.06
Foam EO APRMS	7.3	0.82	6.00
Foam EC APRMS	12.6	0.82	10.35
Level EC MLRMS	5.4	0.82	4.43
Foam EO MLRMS	7.7	0.82	6.32
Foam EC MLRMS	14.7	0.82	12.07
Semi tandem MLRMS	6.8	0.82	5.58
Tandem MLRMS	10.7	0.82	8.79

Kg= Kilogram, PF=plantarflexion, EC= eyes closed, EO=eyes open, APRMS= sway in the anterior posterior direction, MLRMS= sway in the mediolateral directio

Table 3.3: List of standard deviations and difference sizes from different balance and strength variables between the intervention group and the waitlist group

Variables	SD- cross-sectional study	Effect Size	Difference Size
Average Knee Extension (Kg)	7.7	0.71	5.47
Average Hip Abduction (Kg)	7.6	0.71	5.40
Average Ankle PF (Kg)	11.7	0.71	8.31
Level EC APRMS	8.6	0.71	6.11
Foam EO APRMS	7.3	0.71	5.18
Foam EC APRMS	12.6	0.71	8.95
Level EC MLRMS	5.4	0.71	3.84
Foam EO MLRMS	7.7	0.71	5.47
Foam EC MLRMS	14.7	0.71	10.44
Semi tandem MLRMS	6.8	0.71	4.83
Tandem MLRMS	10.7	0.71	7.60

Kg= Kilogram, PF=plantarflexion, EC= eyes closed, EO=eyes open, APRMS= sway in the anterior posterior direction, MLRMS= sway in the mediolateral direction

Table 3.4: List of standard deviations and difference sizes from different balance and strength variables between pre and post intervention for the wait list control group

Variables	SD- cross-sectional study	Effect Size	Difference Size
Average knee Extension (Kg)	7.7	0.41	3.18
Average Hip Abduction (Kg)	7.6	0.41	3.14
Average Ankle PF (Kg)	11.7	0.41	4.83
Level EC APRMS	8.6	0.41	3.55
Foam EO APRMS	7.3	0.41	3.01
Foam EC APRMS	12.6	0.41	5.20
Level EC MLRMS	5.4	0.41	2.23
Foam EO MLRMS	7.7	0.41	3.18
Foam EC MLRMS	14.7	0.41	6.07
Semi tandem MLRMS	6.8	0.41	2.81
Tandem MLRMS	10.7	0.41	4.42

Kg= Kilogram, PF=plantarflexion, EC= eyes closed, EO=eyes open, APRMS= sway in the anterior posterior direction, MLRMS= sway in the mediolateral direction

4.0 PSYCHOMETRIC PROPERTIES OF BALANCE AND STRENGTH MEASUREMENTS IN INDEPENDENT LIVING OLDER ADULTS

4.1 INTRODUCTION

The population of the United States will age dramatically over the next several decades. In 2050, the size of the population aged 65 and over is projected to be about 83.7 million, almost double the estimate of 43.1 million in 2012,[1] and will represent nearly 20% of the total U.S. population.[2] With the increased number of older adults over the age of 65, the number of falls, fall-related injuries and deaths, and associated treatment costs will also rise significantly.[3] Falls are among the most serious public health problems facing older adults.[8] In persons over 65 years, more than one-third of community-dwelling adults fall each year, and half will experience recurrent falls.[8] Older adults who live in long-term care facilities have a greater falls risk and more likelihood of acquiring an injury compared to individuals who live in their community homes.[7] Falls have been associated with high rates of morbidity, reduced function, decreased quality of life, and premature nursing home and hospital admissions.

Normal aging is related to declines in several body systems including cardiovascular, sensory, musculoskeletal, and cognitive function, all of which have been associated with increased risk of falling.[14–16] It is well documented that aging itself also is associated with a decrease in muscle strength, balance, and functional mobility.[17] Maintaining mobility is important for active aging and in preserving community independence; it is also related to better health status and quality of life.[18] Preserving postural stability is also imperative for elderly people to perform activities of daily living safely and independently within their society and thereby avoiding falls.[19] Lower-extremity muscle weakness and balance impairment are risk factors that contribute to mobility limitations and falls in older adults.[7,20]

Because maintaining body balance and mobility is important to successful aging, the assessment of balance and muscle strength are important for identifying older adults who are at high risk of falling, and then developing an exercise intervention to address any impairments. Reliable and valid assessment instruments are necessary to obtain consistent and repeatable measurements for static standing balance and muscle strength. Several methods have been developed to assess balance in older adults. Currently, the most common methods to examine balance in clinical settings include performance-based measures yet the performance based measure have been shown to have examiner's bias,[28] suffer from floor and ceiling effects,[29] cover limited aspects of balance, and often lack sensitivity to detect small changes in balance.[30] These drawbacks are major concerns for both clinicians and researchers who treat balance impairments and investigate the effectiveness of different balance interventions.

Over the last two decades, quantitative assessments of postural sway during standing using tools such as force plates have been used to assess balance and identify postural instability in older adults.[31] Various studies have demonstrated good to excellent reliability for recording postural sway with the use of force plates.[32,33] However, the expense, space requirements, and lack of portability, their clinical utility in the community has been limited.

Recent advances have provided an alternative quantitative method to assess balance that is inexpensive and portable by using body-worn accelerometers. Accelerometers are used to quantify postural sway during standing, and have been shown to have the ability to discriminate between test conditions that require different levels of postural control, between fallers and non-fallers, and young versus older adults.[34–38] Assessing postural stability by using accelerometers has been applied to different populations including people with Parkinson disease,[39] multiple sclerosis,[40] stroke, children, and with community-dwelling older adults.[41,42] Previous studies that have used accelerometers have demonstrated good to excellent test-retest reliability of postural sway measures during the static standing balance.[37,42,201] However, these accelerometer reliability studies were limited to clinical and lab settings, and had not been investigated outside in the community. Recently, a study by Saunders et al.,[38] was published after we had started this project, in which they found good to excellent test-retest reliability for using a tri-axial accelerometer to quantify postural sway in people who live in independent living facilities. Although the Saunders et al. study shares some of the same standing balance conditions, our study had included more standing balance conditions, used a different foam surface, and examined normalized path length as balance parameter.

In addition to postural sway, measures of lower extremity strength are important as potential risk factors for older adults at risk for falling. Currently, best way to measure lower extremity muscle strength is by using computerized isokinetic dynamometry.[43] However, the time demand, expense, and low portability are drawbacks that limit the application of computerized isokinetic dynamometry in independent living facilities. Another method used to assess strength is manual muscle testing. Although it is frequently used to measure muscle strength in the clinic, it lacks adequate psychometric properties, is prone to examiner’s error, and is subject to a ceiling effect.[44,45] Handheld dynamometers have been used in different settings to objectively quantify muscle strength. Even though the portable handheld dynamometry has been proven to be accurate, valid, and reliable in different populations, it has some important limitations, such as difficulty in stabilizing the body part, and the reading is influenced by the strength of the examiner especially for larger muscles.[46,47] The use of uniaxial load cells have been suggested previously, but they have not been used in community-based research settings.[48] A uniaxial load cell device may improve upon the above limitations to quantify muscle strength in different settings.

To bridge the gap between expensive and immobile instruments and task-based measures, and by taking advantage of technological advancements in accelerometers and load cells, postural stability and muscle strength can be quantified portably and inexpensively outside of a lab setting. These tools can serve understudied populations, such as people living in community settings, who may have difficulty getting transportation to research labs, resulting in limited access to this population.[49] Before implementing these inexpensive and portable instruments, it is important to establish the validity, reliability, and the minimal clinically important difference of balance and strength measurements so that clinicians and researchers can identify changes that are important to an individual. The purpose of this study was to examine the test–retest reliability and validity of balance and lower-extremity strength measurements, and to determine the minimal clinically important difference of these measurements after an exercise program.

4.2 METHODS

4.2.1 Design and Subjects

This is an ancillary study of a cluster randomized clinical trial (RCT) that investigated the effect of two different group exercise programs on walking ability and self- reported function and disability. These exercise programs included the On the Move group exercise program that consists of stepping and walking patterns that target timing and coordination of movement during walking, and a standard of care exercise program consisting of seated endurance and strengthening exercises. This study took place from April 2014 to May 2016. Participants in the RCT were invited during their baseline assessment to take part in this study. A total of 131 subjects were enrolled to participate in this study. For the test–retest reliability, a subsample of 38 subjects returned back after one week to take part in a retest session. The convergent validity of balance and lower-extremity strength measurements with different mobility measurements such as the Six-Minute Walk Test (6MWT),[232] gait speed,[235] Figure-of-8 Walk Test (F8WT),[236] Short Physical Performance Battery (SPPB),[229] Gait Efficacy Scale (GES),[237] and repeated chair-stands test[243] was examined for all subjects at baseline. The minimal clinically important difference (MCID) was estimated using data from all subjects, using both distribution and anchor-based approaches.[211] All subjects signed a consent form approved by the University of Pittsburgh Institutional Review Board prior to participation.

Inclusion and exclusion criteria followed that of the parent study. The inclusion criteria were: (1) 65 years of age or older; (2) a resident of a University of Pittsburgh Medical Center (UPMC) independent living facility (ILF), senior high rises, or a senior community center; (3)

ability to ambulate independently within the household with or without a straight cane; and (4) gait speed greater than or equal to 0.60 m/s. Subjects were excluded if they had one or more of the following exclusion criteria: (1) non-English speaking; (2) impaired cognition, which is defined as the inability to follow two-step commands or understand the informed consent process; (3) plans to leave the area for an extended period of time over the next four months; (4) a progressive neuromuscular disorder such as Parkinson disease or multiple sclerosis; (5) any acute illness or medical condition that was not stable; or (6) an inappropriate response to the 6MWT (i.e. exercise heart rate ≥ 120 bpm, exercise systolic BP ≥ 220 or SPB >10 mmHg, or drop in diastolic BP ≥ 110 mmHg).

4.2.2 Balance Accelerometry

The accelerometer was developed as a part of the National Institutes of Health (NIH) Toolbox project as a balance measurement [42]. The dual axis accelerometer (ADXL213AE, with range of ±1.2 g and resolution of 1mg; Analog Devices, Inc., Norwood, MA) is oriented to record mediolateral and anteroposterior acceleration of the body. The acceleration is transmitted via a Bluetooth transmitter to a laptop computer at 50 Hz. A custom written Labview program was used to acquire the data. The system was affixed to the subject's lower back at the level of the iliac crest using Velcro and a gait belt.

4.2.3 Uni-axial Load Cell device

A uni-axial load cell (Measurement Specialties XTC Series) was used to measure lower extremity strength. The load cell has a maximum capacity of 2225 N. The load cell was connected to an amplifier that displayed the instantaneous and maximum force exerted on the load cell. The load cell is arranged in series with straps (two cuffs) that fit around the limb on one end and a stable object on the other end **(Figure 4.1)**

Figure 4.1: A load cell transducer and amplifier on the left. On the right the load cell is attached to subject's legs to measure seated hip abductor muscle strength.

4.2.4 Study Protocol

Subjects attended two testing visits for the test–retest reliability assessment with one week apart. The experimental study group from which they were selected was not controlled. The two visits included both balance and strength measurements. In order to examine convergent validity, balance and strength measurements were collected at baseline along with other mobility measures that were collected by investigators from the parent study. These measures include the 6MWT, gait speed, F8WT, the repeated chair-stands test, GES, and the SPPB. In order to determine the MCID of the balance measures, an anchor-based method was used by asking subjects to rate how they perceived their balance using a change in global rating of state (GRS) at two time points; at baseline prior to the exercise program, and at the end of the program.

For the standing balance measurements, an accelerometer was attached to the subject's lower back while performing the following: (1) standing with feet together on a firm surface with eyes open; (2) standing with feet together on a firm surface with eyes closed; (3) standing with feet together on a foam surface with eyes open; (4) standing with feet together on a foam surface with eyes closed; (5) standing with a semi-tandem stance (one foot halfway in front of the other) on a firm surface with eyes open; and (6) standing with a tandem stance on a firm surface with eyes open. The foam surface that was used in the testing consisted of an AIREX® Balance Pad (Alcan Airex AG, Switzerland), and the foam pad thickness was 6 cm. For the semi-tandem and tandem stance conditions, the subjects placed their feet according to their preference.[230]

Strength measurements included three maximum voluntary isometric contractions (MVIC) for knee extension, hip abduction, and ankle plantarflexion, in this order. All of the testing was done in the sitting position; details about the device positions for each muscle group are summarized in **Table 4.1** Words of motivation were consistent throughout the testing to make sure that the maximum contraction was produced at every testing session. A thirty second rest was provided between trials. The average of the three trials was used in the data analysis. All of the measurements were taken by a physical therapist. To standardize which leg was tested, the dominant foot was determined by asking the subjects about the foot that they would use to kick a ball.[231] Hip abductor strength was assessed bilaterally due to the lack of fixed object.

Table 4.1: Testing positions for strength measurements

Isometric Action	Testing Device Position
Hip abduction	One cuff was placed proximal to the right knee and the other cuff proximal to the left knee. In the sitting position, starting with knees together, the subject was asked to move both knees apart gradually until he/she reached the maximum force over the course of five seconds.
Knee extension	One cuff of the device was placed at the bottom of chair leg and the other cuff around the subject's dominant leg just above the ankle. In the sitting position, the subject was asked to extend the knee gradually until he/she reached the maximum force over the course of five seconds.
Ankle plantarflexion	With the knee of the dominant leg extended in sitting, one cuff was placed at the top of the dominant foot right below the toes and the examiner held a bar with the other cuff attached to it. Subjects were asked to plantarflex his/her ankle gradually until he/she reached the maximum force over the course of five seconds.

4.2.5 Outcome Measures for the Convergent Validity

Six-Minute Walk Test (6MWT):

The Six-Minute Walk Test (6MWT) is a well-validated measure of walking capacity. It was used to assess walking endurance by measuring the maximum distance a person can walk (in meters) in six minutes, including time for rest as needed.[232] The 6MWT is reported to have excellent test–retest reliability (Pearson r = 0.95) in older adults.[233] A change in walking distance of 20 m has been proposed as a small meaningful change, and 50 m as a substantial meaningful change.[234] Better performance is indicated by a greater distance covered during six minutes.

Gait speed:

Subjects were asked to walk at their usual, self-selected speed on an instrumented walkway. The instrumented walkway was 0.61 m wide and 4.27 m long and had pressure sensors embedded within its length to detect and capture data as the individual walked on the walkway. After two practice trials, participants completed six passes that were used for data collection. Gait speed was averaged over the six passes. The test–retest reliability of gait speed measured using an instrumented walkway is excellent (ICC = 0.98 in older adults).[235] A change of 0.10 m/s in gait speed has been indicated as a substantial clinically meaningful change.[234]

Figure-of-8 Walk Test (F8WT):

The Figure-of-8 Walk Test (F8WT) was used to measure motor skill in walking. Participants walked a figure of eight pattern at their self-selected speed around two cones placed 1.5 meters apart. Time and number of steps to complete the F8WT were recorded. A stopwatch was used to count total time taken (sec). The F8WT has established excellent psychometric properties in older adults, inter-rater reliability (ICC=0.90 for time and ICC=0.92 for number of steps) and validity by comparison to measures of gait, motor control and function.[236] Longer time and higher number of steps indicate worse skill in walking.[236]

Repeated Chair Stands test:

As part of the SPPB, participants were asked to perform five consecutive sit to stands as quickly as possible with their arms crossed in front of their chest. This test has been used as a proxy measure of lower extremity strength. Time required to complete the task was recorded. The repeated chair stand test has high test-retest reliability in community dwelling older adults (ICC = 0.96).[243]

Gait Efficacy Scale (GES):

The Gait Efficacy Scale (GES) is a self-reported 10-item scale that addressing older adults' perception of their level of confidence in walking during challenging circumstances including walking over different surfaces, curbs, or stairs. Items are scored on a 10-point Likert scale with 1 denoting no confidence, and 10 for complete confidence, with a possible total score of 100. The test-retest reliability of the GES was ICC=0.93 in community dwelling older adults.[237]

Short Physical Performance Battery (SPPB):

The SPPB was developed as a measure of physical performance for a longitudinal study of aging conducted by the National Institutes on Aging.[229] The SPPB measures three aspects of functional mobility: the time to perform five consecutive transfers from sitting to standing (chair stands), time to ambulate on level surfaces for 4 meters, and the ability to stand with decreasing medial-lateral base of support. Scores from 0 to 4 are assigned to each of the tasks based on quartile scores of the timed chair stands and ambulation, and degree of difficulty of the standing balance test. A summary performance score is equal to the sum of the three sub-scores. Lower scores on the SPPB are associated with elevated risk of death,[229] nursing home admission, incident self-reported disability in ADLs and mobility. The duration of testing is 15 minutes. The test-retest reliability of the SPPB over 4 to 7 days ranged from 0.83 to 0.89 in older adults aged 65 to 74,[238] and 0.72 in older adults with mean age of 74 over two week period.[239]

Anchor-based measures:

The anchor-based measure for balance accelerometry was obtained by a change in the Global Rating of State (GRS) in balance scale. Subjects were asked at the beginning of the exercise intervention and at the end to evaluate their balance. The question was stated as, "Would you say your balance in general is excellent, very good, good, fair, or poor?” The response was made on 5-point Likert scale as follows; 1 = excellent; 2 = very good; 3 = good; 4 = fair; and 5 = poor. The difference between responses at the beginning and at the end was calculated. A small decline was defined as a decrease by one point (-1), small improvement as an increase by one point (1), substantial improvement as an increase by 2 or 3 points, and substantial decline as decrease by 2 or 3 points. The lack of an anchor measure for strength prevented us from computing the MCID for the strength measures using an anchor-based approach.

4.2.6 Data Analysis

4.2.6.1 Balance Accelerometry (BA)

The first and last five seconds of the recording were not included in the analysis in order to eliminate transient effects.[240] Using a custom written Matlab program, the acceleration data were lowpass filtered using a 4th order Butterworth filter with a cutoff frequency of 2 Hz. The cutoff frequency calculation was based on the Nyquist sampling theorem, which states that sampling frequency should be at a frequency greater than twice as high as the highest frequency contained in the signal.[241] A cutoff frequency of 2 Hz is sufficient to capture the physiological sway, since postural sway during quiet standing is typically restricted to low frequencies (<1 Hz).[242]

The Root Mean Square (RMS) and the Normalized Path Length (NPL) were calculated for both directions, the anteroposterior (AP) and mediolateral (ML) directions; a higher value indicates more sway. The RMS and NPL were calculated as follows:

$$RMS = \sqrt{\frac{\left(\sum_{j=1}^{N-1} P_j\right)^2}{N}} \quad \text{mG} \quad (1)$$

$$NPL = \frac{1}{t} \sum_{j=1}^{N-1} \left|p_{j+1} - p_j\right| \quad \text{mG/s} \quad (2)$$

where t is the time duration, N is the number of time samples, and p_j is the acceleration data at time sample j. The mG stands for milli-Gravitational acceleration, where 1 mG = 0.0098 m/s^2 and mG/s is the milli-Gravitational acceleration divided by the time duration in s.

4.2.7 Statistical Analysis

4.2.7.1 Overview

Data was analyzed using SAS software version 9.4 (SAS Institute, Inc., Cary, NC). Balance and strength data were inspected visually using histograms and descriptive statistics to examine the normality of the distribution. Descriptive statistics of subject demographic characteristics were reported. In this study, Shapiro-Wilk revealed a non-normal distribution of the acceleration and the strength data, hence Wilcoxon signed-rank test was used to examine the existence of systematic bias.[210] The level of statistical significance was set at $\alpha = 0.05$ for all analyses.

4.2.7.2 Reliability

Test–retest reliability one week apart was estimated for both balance accelerometry measurements and lower extremity muscle strength. Intraclass correlation coefficients (ICC, model 3.1, two-way mixed-effects model) and 95% confidence intervals (95% CI) were calculated to examine the relative reliability. The ICC was defined as the ratio of between-subject variability to the total variability. The ICC index ranges from 0 to 1; values that are closer to 1 represent a higher reliability. Values of the ICC from 0.40 to 0.75 indicate fair to good, and values greater than 0.75 represent excellent reliability whereas values less than 0.40 indicate poor reliability.[200]

4.2.7.3 Validity

Face validity was examined by examining how body sway changed as the balance conditions became more difficult. These balance conditions were chosen to alter sensory feedback and reduce the base of support. The Shapiro-Wilk test revealed a non-normal distribution of the acceleration and the strength data, hence the Friedman test was used to examine if significant differences existed in the among balance tasks. Post hoc pairwise comparisons were made with Wilcoxon signed ranks tests. The convergent validity of the measurements was examined by calculating the correlation of balance and strength measurements with the mobility measurements at the initial baseline assessment. Spearman's rank correlation coefficients were used to examine the relationship between postural sway and muscle strength measurements with the various mobility measurements: the 6MWT, gait speed, GES, F8WT, SPPB and SPPB balance, and repeated chair-stands test.

4.2.7.4 Minimal Clinically Important Difference (MCID)

Two methods were used to estimate the MCID score, including distribution-based and anchor-based approaches.

1. Distribution-based approach:

Distribution-based measures of the minimal clinically important difference include the effect size and SEM for both balance and muscle strength measurements. The effect size (ES) estimate was based on the standard deviation of each outcome measurement for all subjects (n=131); a small ES was computed as 0.2 × SD, and a substantial ES was computed as 0.5 × SD.[211] The SEM was calculated using the standard deviation (SD) and the ICC as follows: (SEM = SD $\sqrt{}$ (1 – ICC)).[211] The SEM was calculated for the whole sample (n=131).

2. Anchor-based approach:

Comparison of Mean Change

A linear mixed model using the SAS MIXED procedure was used to compare the difference in mean change in postural acceleration measures over time, with the change in GRS over time. Subjects were classified into three groups based on having no change (n=66), a small decline (n=30), or small improvement (n=28) in GRS score. Subjects with missing values were excluded from the analysis. Subject was included in the model as a random effect.

4.3 RESULTS

Demographic and clinical characteristics of the study sample are summarized in Table 4.2. For the validity sample, 84% were female, and average age was 80 (SD 7.7) years. Fifty-three percent of the entire sample had at least some college education. Eighty-eight percent of the sample had a musculoskeletal condition; 79% had visual or hearing dysfunction; and 18% had diabetes. The subsample that had reliability testing were younger than the whole sample, had less hearing or visual impairment, but a greater prevalence of diabetes.

Table 4.2: Demographic and clinical characteristics of subjects

Variable	**Validity Sample (n=131)**	**Reliability subsample (n=38)**
Age, years	80.3 (7.7)	76.4 (6.5)
Female, n (%)	111 (84.7)	33 (86.8)
Race		
White n (%)	110 (83.9)	31 (81.5)
Married, n (%)	28 (21.3)	6 (15.7)
Education, [a] n (%)	70 (53.4)	18(47.3)
Chronic conditions		
Cardiac, n (%)	24 (18.3)	9 (23.6)
Musculoskeletal, n (%)	115 (87.7)	33 (86.8)
Visual/Hearing, n (%)	104 (79.3)	24 (63.1)
Diabetes, n (%)	24 (18.3)	13 (34.2)
Cancer, n (%)	28 (21.3)	8 (21.1)
Lung, n (%)	41 (31.2)	13 (34.2)
Total comorbidity		
> 3 conditions, n (%)	40(30.5)	16 (42.1)
< 3 conditions, n (%)	91(69.4)	22 (57.9)

[a]: was defined as attended at least some college

Test–retest reliability

A Wilcoxon signed-rank test showed no significant difference between the means of the test and retest sessions across all balance and strength measurements indicating no systematic bias was detected. The results of the test–retest reliability analyses are presented in Table 4.3 and 4.4.

Table 4.3 shows the ICCs values with their corresponding confidence intervals for test–retest reliability of balance accelerometry measurements (RMS and NPL sway in AP and ML directions) for all standing balance conditions. The ICCs were all good to excellent with values ranging from 0.41 to 0.83 for RMS sway and from 0.49 to 0.81 for NPL sway, except for the AP measures during semi-tandem stance, which demonstrated an atypical increase in sway during the second test, resulted in a poor reliability during this condition. After taking the average ICC for the included sway parameters, the ML NPL sway measures showed the highest ICC with an average of 0.73 **(Table 4.3).**

Table 4.4 represents the ICC values for test–retest reliability for lower-extremity strength measurements using a uniaxial-load cell device. The ICCs after averaging three consecutive trials for knee extensors, hip abductors, and ankle plantarflexors were excellent (ICC= 0.95, 0.99, and 0.90, respectively). The output from single trial showed lower ICC values but remains above >0.75 indicating excellent reliability (**Table 4.4).**

Table 4.3: Mean (SD) of balance accelerometry measurements and test–retest reliability, indicated by the intraclass correlation coefficient (ICC), 95% confidence interval, and p-values from the Wilcoxon signed ranks test, (n=38).

Balance Conditions		Mean test ±SD	Mean retest ± SD	P-value	ICC (CI 95%)	ICC average
AP RMS	**Level EO**	7.51 ± 2.21	7.50 ± 2.40	0.95	0.81 (0.67-0.89)	0.61
	Level EC	8.57 ± 2.61	8.55 ± 2.27	0.92	0.58 (0.33-0.76)	
	Foam EO	7.70 ± 2.66	8.03± 2.70	0.18	0.77 (0.60-0.87)	
	Foam EC	11.70 ± 3.64	11.90 ± 4.30	0.89	0.63 (0.40-0.79)	
	Semi-tandem	7.91± 2.81	9.00± 3.51	0.09	0.41 (0.11-0.64)	
	Feet tandem	9.10± 4.73	8.65± 3.95	0.83	0.47 (0.18-0.68)	
ML RMS	**Level EO**	4.87 ± 2.02	4.43 ± 2.02	0.13	0.67 (0.47-0.82)	0.63
	Level EC	5.77 ± 2.30	5.94 ± 2.44	0.63	0.55 (0.28-0.74)	
	Foam EO	6.77 ± 2.93	7.11 ± 3.10	0.56	0.55 (0.28-0.73)	
	Foam EC	11.94 ± 5.42	12.07 ± 4.40	0.77	0.52(0.25-0.72)	
	Semi-tandem	5.18 ± 2.03	5.49 ± 2.18	0.21	0.83 (0.71-0.91)	
	Feet tandem	5.54 ± 2.78	5.77 ± 2.57	0.46	0.71 (0.51-0.84)	
AP NPL	**Level EO**	10.28 ± 3.36	10.57 ± 3.18	0.17	0.66 (0.44-0.81)	0.64
	Level EC	14.53± 5.05	15.05 ± 5.88	0.70	0.66 (0.44-0.81)	
	Foam EO	11.24 ± 3.41	11.06 ± 3.57	0.80	0.71 (0.51-0.84)	
	Foam EC	17.62 ± 6.29	17.68 ± 6.14	0.93	0.82 (0.67-0.90)	
	Semi-tandem	13.44 ± 4.75	14.85 ± 5.50	0.23	0.35 (0.04-0.60)	
	Feet tandem	14.72 ± 6.41	15.63 ± 6.15	0.18	0.65 (0.41-0.80)	
ML NPL	**Level EO**	10.43 ± 4.66	10.61 ± 4.35	0.67	0.61 (0.37-0.78)	0.73
	Level EC	13.99 ± 7.34	14.22 ± 6.22	0.82	0.79 (0.64-0.88)	
	Foam EO	15.30 ± 7.07	15.87 ± 6.15	0.27	0.71 (0.50-0.83)	
	Foam EC	24.09 ± 13.00	23.61 ± 9.81	0.74	0.81 (0.67-0.90)	
	Semi-tandem	14.43 ± 6.84	15.74 ± 5.87	0.18	0.71 (0.51-0.84)	
	Feet tandem	17.31 ± 7.66	18.33 ± 7.27	0.46	0.73 (0.54-0.85)	

Eyes Open: EO, Eyes Closed: EC, root-mean-square: RMS, normalized path length: NPL, antero-posterior: AP and mediolateral: ML. RMS sway (mG), and NPL sway (mG/s).

Table 4.4 :Mean (SD) lower extremity strength performance and test–retest reliability, indicated by the intraclass correlation coefficient (ICC), 95% confidence interval, p-values fromWilcoxon signed ranks test, (n=38)

Isometric Action (N)	Mean test ±SD	Mean retest ± SD	ICC (CI 95%) (Average 3 trials)	ICC (CI 95%) (Single trial)	P
Hip Abduction	184 ± 64	186 ± 63	0.99 (0.97-0.99)	0.95 (0.89-0.97)	0.35
Knee Extension	204 ± 61	207 ± 59	0.95(0.90-0.97)	0.91 (0.85-0.96)	0.39
Ankle Plantarflexion	198 ± 68	205 ± 63	0.90 (0.81-0.95)	0.89 (0.81-0.94)	0.09

Validity

In order to demonstrate face validity of the acceleration measures, we observed an increase in RMS and NPL sway in both directions as the difficulty of the balance conditions increased with eyes closed versus open, and foam versus firm surface **(Figure 4.2)**. First, the effect of vision (eyes open vs. eyes closed) was examined for each of the surface conditions **(Table 4.5).** While standing on the firm surface, subjects had a significant increase in sway for eyes closed compared with eyes open, in three out of the four acceleration measures (ML RMS, AP NPL, and ML NPL). On the foam surface, there was a significant increase in sway for all four of the sway measures. Next, we tested the effect of surface (firm vs. foam) for each of the vision conditions. With eyes open, there was a significant increase in sway on foam compared with firm only for acceleration in the ML direction. However, with eyes closed, all four of the sway measures demonstrated an increase in sway during the foam condition **(Table 4.5).**

In order to demonstrate the convergent validity with other mobility measures, Table 4.6 shows the Spearman's rank correlation coefficients between the RMS sway and NPL sway, with different mobility measurements including the 6MWT, gait speed, F8WT, GES, and repeated chair-stands test. The table is ordered according to the mobility measurements that have the greatest number of significant correlations. There was a statistically significant correlation between the amount of RMS and NPL sway in the AP and ML directions with the SPPB balance component, in 22/24 parameters (Spearman's rho ranged from −0.17 to −0.44, $p < 0.05$). For most of the measures the correlation slightly decreased when examining the total score of the SPPB. The GES was significantly correlated with 15/24 of the RMS and NPL sway measures. The highest correlation coefficients were during semi-tandem and tandem stances, and when on a foam surface with EO. The relationship was in the expected direction, such that as the sway increased, the confidence in walking decreased (Spearman's rho ranging from −0.19 to −0.41, $p < 0.05$). The NPL sway in the AP direction during semi-tandem and tandem stances was significantly correlated with repeated chair rise time (Spearman rho = 0.21, and 0.24, $p < 0.01$). Gait speed, 6MWT, and F8WT were significantly correlated with acceleration measures in about one-half of the cases, with the foam EO and tandem conditions most frequently demonstrating significant relationship. Better mobility test performance was associated with less sway **(Table 4.6).**

Table 4.7 shows the Spearman's rank correlation coefficients between lower extremity strength, and the different mobility measurements. The strongest correlations demonstrated that greater lower extremity strength was related to less time to complete the repeated chair-stand test with Spearman's rho ranging from –0.33 to –0.38, $p < 0.01$. In addition, ankle plantarflexion strength had the highest correlation with the SPPB (Spearman's rho =0.38, $p < 0.05$). In general, greater lower extremity strength was related to better gait self-efficacy, and better performance in the F8WT, 6MWT, and gait speed tests **(Table 4.7).** Finally, all included muscle groups were significantly correlated with height and weight except knee extensor strength (Table 4.7).

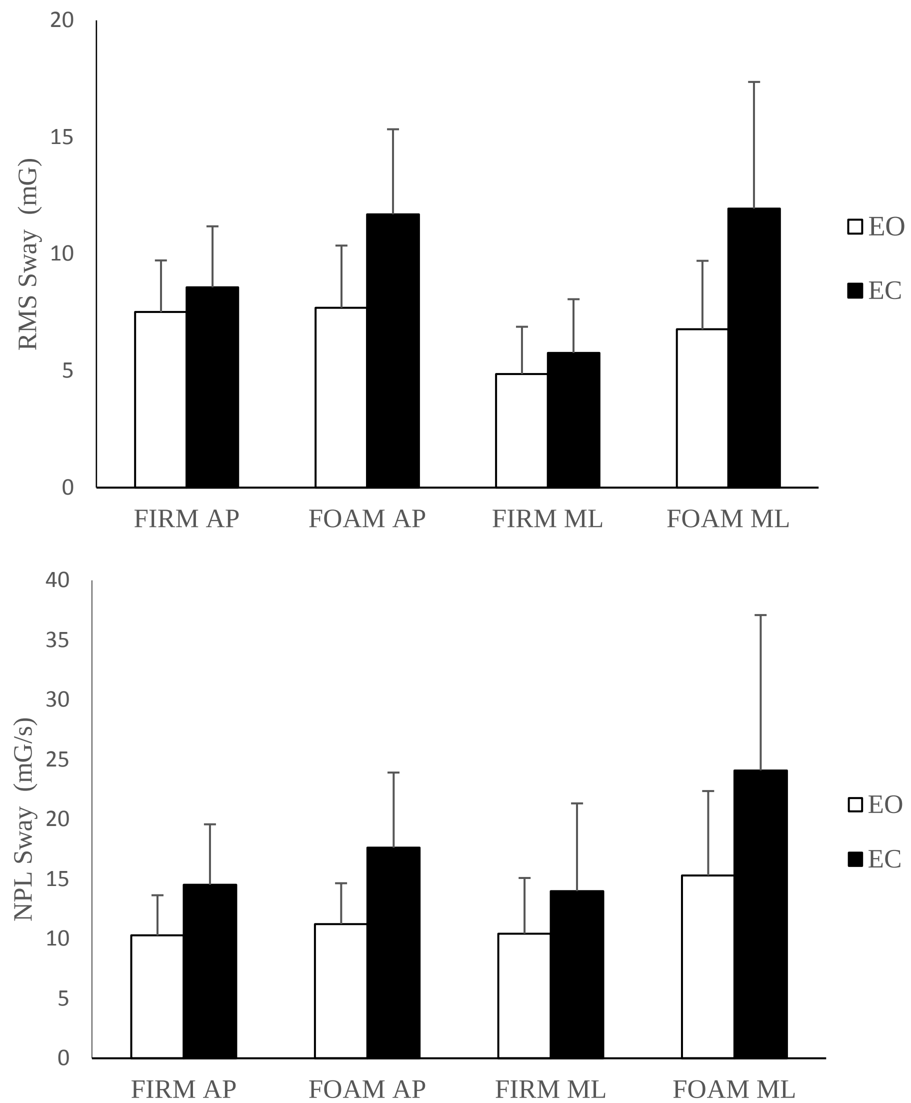

Figure 4.2: Effect of vision (Eyes Open: EO, and Eyes Closed, EC) and surface conditions (Firm, Foam) on root-mean-square (RMS, Top) and normalized path length (NPL, Bottom) sway acceleration for antero-posterior (AP) and mediolateral (ML) directions. (Error bars represent + 1 standard deviation); mG: milli-Gravitational acceleration, mG/s: milli-Gravitational acceleration divided by time duration; (n = 131).

Table 4.5: Balance conditions that showed signifcant differences between the firm and foam surfaces and between eyes open and closed for both the RMS and NPL sway; (n = 131).

Balance conditons	**RMS**		**NPL**	
	AP	**ML**	**AP**	**ML**
Firm, EO vs. EC	P = 0.078	**P = 0.035**	**P< 0.001**	**P< 0.001**
Foam, EO vs. EC	**P< 0.001**	**P< 0.001**	**P< 0.001**	**P< 0.001**
EO, Firm vs. Foam	P = 0.948	**P< 0.001**	P = 0.070	**P< 0.001**
EC, Firmvs. Foam	**P< 0.001**	**P< 0.001**	**P = 0.011**	**P< 0.001**

RMS: root mean square; NPL: normalized path length; AP: anterior-posterior direction; ML: medial-lateral direction

Table 4.6: Spearman rank correlation coefficients between balance accelerometry conditions and the Short Physical Performance Battery balance (SPPB_b) and total (SPPB_t) scores, Gait Efficacy Scale (GES), Figure of 8 Walk Test (F8WT), Six-Minute Walk Test (6MWT), gait speed and Repeated Chair Stands (N=131).

Balance Conditions		SPPB_b	SPPB_t	GES	F8WT	6MWT	Gait speed	Chair stands
AP RMS	**Level EO**	-0.17*	-0.24**	-0.10	0.07	-0.08	-0.07	0.13
	Level EC	-0.30**	-0.24**	-0.19*	0.09	-0.06	-0.10	0.11
	Foam EO	-0.35**	-0.33**	-0.26**	0.21*	-0.24**	-0.22*	0.13
	Foam EC	-0.24**	-0.08	-0.03	-0.11	0.10	0.11	-0.05
	Semi-tandem	-0.29**	-0.26**	-0.28**	0.02	-0.09	-0.06	0.08
	Feet tandem	-0.33**	-0.28**	-0.25**	0.22*	-0.08	-0.05	0.15
ML RMS	**Level EO**	-0.40**	-0.27**	-0.15	0.12	-0.12	-0.24**	0.09
	Level EC	-0.31**	-0.15	-0.15	0.02	-0.01	-0.10	0.03
	Foam EO	-0.39**	-0.32**	-0.31**	0.23**	-0.27**	-0.28**	0.18*
	Foam EC	-0.15	-0.04	-0.09	-0.11	0.13	0.08	-0.02
	Semi-tandem	-0.43**	-0.30**	-0.26**	0.20*	-0.22*	-0.25**	0.15
	Feet tandem	-0.44**	-0.42**	-0.30**	0.24**	-0.20*	-0.27**	0.23*
AP NPL	**Level EO**	-0.32**	-0.30**	-0.32**	0.27**	-0.19*	-0.24**	0.14
	Level EC	-0.30**	-0.25**	-0.22*	0.15	-0.10	-0.12	0.11
	Foam EO	-0.34**	-0.35**	-0.31**	0.21*	-0.23**	-0.20*	0.18*
	Foam EC	-0.19*	-0.08	-0.08	-0.08	0.12	0.10	0.01
	Semi-tandem	-0.28**	-0.32**	-0.41**	0.31**	-0.27**	-0.19*	0.21*
	Feet tandem	-0.34**	-0.37**	-0.30**	0.27**	-0.14	-0.17	0.24**
ML NPL	**Level EO**	-0.33**	-0.11	-0.17	0.08	-0.02	-0.12	-0.03
	Level EC	-0.28**	-0.06	-0.12	0.01	0.05	-0.04	-0.06
	Foam EO	-0.35**	-0.27**	-0.27**	0.21*	-0.20*	-0.21*	0.14
	Foam EC	-0.14	0.01	0.01	-0.16	0.20*	0.14	-0.05
	Semi-tandem	-0.36**	-0.25**	-0.18*	0.18*	-0.03	-0.13	0.15
	Feet tandem	-0.25**	-0.29**	-0.29**	0.27**	-0.18*	-0.24**	0.14
Number of significant correlations/total		22/24	17/24	15/24	12/24	10/24	10/24	5/24

* indicates significant correlation coefficient $p < 0.05$

**indicates significant correlation coefficient $p < 0.01$.

Table 4.7: Spearman rank correlation coefficients between lower extremity strength and the SPPB, GES, F8WT time, 6MWT, gait speed, repeated chair stands test, height, and weight; (N=131).

Isometric Action (N)	**SPPB**	**GES**	**F8WT**	**6MWT**	**Gait speed**	**Chair-rise time**	**Height**	**Weight**
Knee extension	0.28**	0.21*	− 0.26**	0.24**	0.24*	− 0.33**	0.15	0.36*
Hip abduction	0.29**	0.28**	− 0.25**	0.29**	0.22*	− 0.33**	0.34*	0.37*
Ankle plantarflexion	0.38**	0.22*	− 0.15	0.24**	0.25**	− 0.38**	0.28*	0.24*

*indicates significant correlation coefficient $p < 0.05$.

**indicates significant correlation coefficient $p < 0.01$.

Minimal Clinically Important Difference (MCID) for the Accelerometry Measure

Distribution-based methods

Table 4.8 shows estimates of the MCID based on the effect size analysis for balance accelerometry measurements. A small ES was defined as 0.2 SD which ranged from 0.52 to 2.21 for the RMS, and from 1.07 to 4.12 mG/s for the NPL sway parameters, the largest of which occurred for the foam EC condition. The change in body sway for moderate effects ranged from 1.31 to 5.52 mG for the RMS, and from 2.67 to 10.3 mG/s for the NPL sway parameters. The MCID's increased as the sensory inputs were altered or the base of support decreased. The SEMs for balance conditions ranged from 1.00 to 3.40 mG for the RMS, and from 1.87 to 4.97 mG/s for the NPL sway parameters. Table 4.9 shows the effect size estimates were similar for hip abduction and knee extension strength, and larger for the ankle plantarflexion. The SEM was twice as large for the knee extension compared with hip abduction. The SEM for the ankle plantarflexion was three times higher than hip abduction and 1.5 times greater than the knee extension.

Anchor-based methods

For the Global Rating of State in balance scale, about 22% of the participants (30/136) reported a small decline in balance, 48% (66/136) experienced no change, 20% (28/136) reported minimal improvement, and only 8 subjects reported a large improvement **(Tables 4.10 and 4.11)**. The mean score changes in those participants who were rated as having a small decline (GRS = −1), large decline (GRS = −2), no change (GRS= 0), small improvement (GRS= +1), large improvement (GRS= +2) are shown in Table 4.12. The NPL measures of acceleration more consistently showed the expected changes in sway, related to the GRS category. That is, subjects who had a small improvement in GRS had a mean reduction in sway compared with subjects who had no change in GRS. The reduction in sway occurred in 12/12 of the NPL variables, ranging from -0.07 to -5.8 mG/s. Additionally for the NPL, subjects who were classified as having a small decline had a mean increase in sway that ranged from 0.07 to 15.1 mG/s compared with the no change group. However, there was an unexpected mean increase in sway for the no change group compared with small decline group for the AP NPL sway during semi-tandem and tandem stance.

We compared the results from the anchor-based approach and the distribution-based methods (Table 4.13). There was only one measure in which the anchor-based MCID was greater than the distribution-based SEM pooled from the full sample (n=131): the ML NPL sway during standing on foam eyes closed. In addition, similar results were found when comparing all subjects who reported decline vs no change, and those who reported improvement vs no change (Table 4.14). The relationship between change in the RMS acceleration and GRS was less clear.

Table 4.8: Distribution-Based Meaningful Differences for balance accelerometry measurements; (n = 131).

Balance Conditions		ES small 0.2 SD	ES moderate 0.5 SD	SEM
AP RMS	**Level EO**	0.78	1.94	1.69
	Level EC	1.01	2.53	3.27
	Foam EO	1.55	3.87	3.71
	Foam EC	2.21	5.52	6.71
	Semi-tandem	1.09	2.72	4.18
	Feet tandem	1.33	3.33	4.84
ML RMS	**Level EO**	0.52	1.31	1.51
	Level EC	0.67	1.67	2.25
	Foam EO	1.35	3.38	4.53
	Foam EC	1.94	4.84	6.71
	Semi-tandem	0.63	1.57	1.29
	Feet tandem	1.01	2.52	2.71
AP NPL	**Level EO**	1.07	2.67	3.11
	Level EC	1.78	4.45	5.19
	Foam EO	2.14	5.35	5.76
	Foam EC	3.79	9.48	8.05
	Semi-tandem	1.79	4.47	7.21
	Feet tandem	2.93	7.33	8.67
ML NPL	**Level EO**	1.08	2.71	3.39
	Level EC	1.74	4.34	3.98
	Foam EO	2.68	6.70	7.22
	Foam EC	4.12	10.30	8.98
	Semi-tandem	1.84	4.61	4.96
	Feet tandem	2.35	5.88	6.11

ES: effect size, SD: baseline standard deviation,

SEM: standard error of measurement using the standard deviation of the reliability sample (n=131)

Table 4.9: Distribution-Based Meaningful Differences for lower extermity strength (n= 131)

Isometric Action (N)	ES small 0.2 SD	ES moderate 0.5 SD	SEM
Hip Abduction	13.55	33.88	6.78
Knee Extension	12.77	31.93	14.28
Ankle plantarflexion	17.75	44.38	28.07

ES: effect size, SD: baseline standard deviation, SEM: standard error of measurement

SEM: standard error of measurement using the standard deviation of the reliability sample (n=131)

Table 4.10: Number of subjects as they rated their balance on the global rating of state (GRS) from baseline to posttesting.

		Final GRS				
		1	**2**	**3**	**4**	**5**
Baseline GRS	**1**	4	4	1	1	0
	2	3	24	10	1	0
	3	2	11	25	14	0
	4	1	6	12	12	2
	5	0	0	0	2	1

* Black shaded cells indicate subjects who reported no change, light gray shaded cells indicated subjects who demonstrated improvement by 1 point, dark gray shaded cells indicated a decline by 1 point, blue shaded cell indicated substantial improvement, and red shaded cell indicated substantial decline (GRS: global rating of state)

Table 4.11: Number of subjects with no change, a small decline, and a small improvement in response to Global Rating of State in balance scale across intervals.

Self-Report Anchor	Intervals [a]	Small Decline (n)	No Change (n)	Small Improvement (n)
Global Rating of State in balance scale	1–2	10	16	8
	2–3	7	20	6
	1–3	13	30	14
Total (n)		30	66	28

[a]: 1-2 (baseline1 to baseline2), 2-3 (baseline2 to post-testing), and 1-3 (baseline1 to post-testing)

Table 4.12: Anchor-Based meaningful change estimates for balance accelerometry measurements.

Balance Conditions		Small decline (n=30) (-1)	No change (n=66) (0)	Small Improvement (n=28) (+1)	MCID (No change vs Small Decline)	MCID (No change vs Small Improvement)
AP RMS	**Level EO**	0.16	0.69	− 0.76	− 0.53	− 1.45
	Level EC	**1.91**	**− 2.09**	**− 2.41**	**4.00**	**− 0.32**
	Foam EO	− 1.39	− 2.53	− 1.95	1.14	0.58
	Foam EC	− 2.39	− 3.33	− 3.09	0.95	0.25
	Semi-tandem	− 0.84	− 0.81	− 1.22	− 0.03	− 0.41
	Feet tandem	− 2.04	− 1.27	− 2.21	− 0.77	− 0.95
ML RMS	**Level EO**	− 0.31	0.51	− 0.15	− 0.82	− 0.66
	Level EC	**− 0.34**	**− 0.56**	**− 0.74**	**0.22**	**− 0.18**
	Foam EO	0.32	− 2.21	− 1.08	2.52	1.13
	Foam EC	**2.68**	**− 4.94**	**− 5.74**	**7.62**	**− 0.80**
	Semi-tandem	**− 0.33**	**− 0.79**	**− 0.85**	**0.46**	**− 0.06**
	Feet tandem	0.49	− 0.11	− 0.63	0.59	− 0.51
AP NPL	**Level EO**	**0.44**	**0.18**	**− 1.02**	**0.26**	**− 1.21**
	Level EC	**− 0.02**	**− 0.84**	**− 3.69**	**0.83**	**− 2.85**
	Foam EO	**− 1.41**	**− 2.41**	**− 3.92**	**1.00**	**− 1.51**
	Foam EC	**− 0.23**	**− 4.60**	**− 10.40**	**4.37**	**− 5.80**
	Semi-tandem	− 1.30	− 0.53	− 3.27	− 0.77	− 2.74
	Feet tandem	− 3.46	− 1.13	− 3.58	− 2.34	− 2.45
ML NPL	**Level EO**	**0.16**	**0.10**	**0.03**	**0.07**	**− 0.07**
	Level EC	**− 0.07**	**− 0.54**	**− 1.97**	**0.47**	**− 1.43**
	Foam EO	**2.02**	**− 4.10**	**− 4.49**	**6.11**	**− 0.39**
	Foam EC	**4.51**	**− 10.55**	**− 12.94**	**15.06**	**− 2.39**
	Semi-tandem	**− 0.33**	**− 1.44**	**− 2.03**	**1.11**	**− 0.59**
	Feet tandem	**1.80**	**− 3.17**	**− 3.73**	**4.97**	**− 0.56**

Table 4.13: A comparison between anchor-based approach and distribution-based methods for the NPL sway measures

Balance Conditions		MCID (No change vs Small Decline)	MCID (No change vs Small Improvement)	0.2 SD	0.5 SD	SEM
AP NPL	Level EO	0.26	− 1.21	1.07	2.67	3.11
	Level EC	0.83	− 2.85	1.78	4.45	5.19
	Foam EO	1.00	− 1.51	2.14	5.35	5.76
	Foam EC	4.37	− 5.80	3.79	9.48	8.05
	Semi-tandem	− 0.77	− 2.74	1.79	4.47	7.21
	Feet tandem	− 2.34	− 2.45	2.93	7.33	8.67
ML NPL	Level EO	0.07	− 0.07	1.08	2.71	3.39
	Level EC	0.47	− 1.43	1.74	4.34	3.98
	Foam EO	6.11	− 0.39	2.68	6.70	7.22
	Foam EC	**15.06**	− 2.39	4.12	10.30	**8.98**
	Semi-tandem	1.11	− 0.59	1.84	4.61	4.96
	Feet tandem	4.97	− 0.56	2.35	5.88	6.11

Bold font indicates mean change greater than the SEM (131).

Table 4.14: A comparison between anchor-based approach and distribution-based methods for the NPL sway measures

Balance Conditions		MCID (No change vs Small Decline)[a]	MCID (No change vs Small Improvement)[a]	MCID (No change vs Decline)[b]	MCID (No change vs Improvement)[b]	SEM
AP NPL	Level EO	0.26	− 1.21	0.25	− 0.95	3.11
	Level EC	0.83	− 2.85	0.82	− 2.20	5.19
	Foam EO	1.00	− 1.51	1.00	− 0.42	5.76
	Foam EC	4.37	− 5.80	4.37	− 5.30	8.05
	Semi-tandem	− 0.77	− 2.74	− 0.76	− 2.38	7.21
	Feet tandem	− 2.34	− 2.45	− 2.33	− 4.36	8.67
ML NPL	Level EO	0.07	− 0.07	0.06	− 0.54	3.39
	Level EC	0.47	− 1.43	0.46	− 1.46	3.98
	Foam EO	6.11	− 0.39	6.11	0.55	7.22
	Foam EC	**15.06**	− 2.39	**15.0**	− 1.88	8.98
	Semi-tandem	1.11	− 0.59	1.11	− 0.43	4.96
	Feet tandem	4.97	− 0.56	4.97	− 1.68	6.11

[a]: Small decline and small improvement was defined as change by one point in the GRS
[b]: Decline and improvement was defined as change by one point or more in the GRS

4.4 DISCUSSION

The aims of the present study were to assess the test–retest reliability, examine face and convergent validity, and determine the MCID of balance accelerometry and lower extremity strength measurements in residents of independent living facilities, senior community centers, or high rise apartments. Both balance and strength measurements showed good to excellent reliability in most of measured parameters and were correlated with mobility measurements.

Reliability

Balance Accelerometry

Across the six balance test conditions, the sway measure that produced the greatest reliability was the normalized path length in the mediolateral direction, with ICC scores ranging from 0.61 to 0.81. The reliability of the other 3 measures (i.e. AP RMS, ML RMS, and AP NPL) was approximately equal. In addition, some of the other sway measures had excellent reliability for specific test conditions. For the AP RMS measure, the level and foam eyes open conditions had excellent reliability, as did the semi-tandem for the ML RMS. The AP NPL measures during the foam eyes closed condition also had excellent reliability. Only one measure had poor reliability: the AP NPL during semi-tandem stance. Compared with previous research, the ICCs from the current study were similar in some conditions and higher in others. Published studies that have used an accelerometer to quantify RMS sway, in AP and ML directions, reported ICCs ranging from 0.16-0.71 for standing on a firm surface with eyes open,[37,201–203] compared to an ICC of

0.81 for the AP axis and 0.67 for the ML axis in this study. Previous studies have also documented ICCs for RMS sway ranging from 0.45-0.52 for standing on a firm surface with eyes closed [37,201] compared to an ICC of 0.58 for the AP axis and 0.55 for the ML axis in this study. The current study may have had greater ICC values compared with these previous studies because the age range of our subjects was larger, and thus we may have had greater intersubject variability. However, we also note that the Whitney et al., (2011) study, which included a wider age range of both younger and older adults, showed a lower ICC of 0.16 for RMS sway in the AP direction when standing on a level surface with eyes open and an ICC of 0.46 for eyes closed.

Saunders et al. (2015) reported higher ICCs for RMS sway in both directions than our study,[38] ranging from 0.77-0.93 for standing on a firm surface with eyes open and closed compared to ICCs ranging from 0.55-0.81 in the current study. Also in the Saunders study, the ICCs for standing on foam surface ranged from 0.76-0.95; our ICCs during standing on foam surface ranged from 0.52-0.77. There are several possible reasons for the higher reliability in the Saunders study. In the Saunders study, they used the average of three trials for each balance condition, which would increase the ICC value compared to one trial in our study. It has been shown previously that test–retest reliability increased as the number of trials increase.[244,245] In the present study, to avoid fatigue of the elderly participants, only one trial was done. In addition, the retest session for the Saunders study was conducted within the same day. Evaluating test–retest reliability within-day has been shown to improve the ICC estimate as compared to between-day estimation.[202] Finally, they used a different foam surface than we used, and foam density and thickness can affect postural stability.[246]

Our results for the NPL parameters were consistent with previous studies [42,204] that used similar accelerometers for standing on a foam surface with eyes open and eyes closed in the AP direction with ICCs of 0.74, and 0.82, respectively. However, our results in these two conditions were slightly lower than results from Rine et al., (2013) [42] who reported an ICC of 0.88 for standing on foam with eyes open and 0.87 with eyes closed. Although a similar foam pad was used in this study, the retesting was done within the same day which could have yielded these higher ICC values.

The test–retest reliability during standing in semi-tandem and tandem stance was higher for the ML direction as opposed to the AP directions for both RMS and NPL sway. For the NPL sway, it is possible that greater reliability was due in part because of greater intersubject variability; however, greater variability was not observed for the ML RMS compared with the AP RMS sway. The semi-tandem and tandem stance conditions two specific conditions place more emphasis on the control of stance in the ML direction than AP, which seems to be more clinically relevant as ML sway has been associated with fall history in previous studies.[247,248] Similarly, Moe-Nilssen et al found higher ICCs for RMS acceleration in the ML (ICC=0.84) than AP (ICC=0.69) during standing on one foot where the base of support is more limited in the ML direction, thus providing support to our current findings during semi-tandem (ICC=0.83 for ML RMS versus 0.41 for AP RMS), and tandem stance (ICC=0.71 for ML RMS versus 0.47 for AP RMS).[201]

The balance accelerometry measurements could be improved by modifying the protocol to include the average of multiple trials, and adding a practice session before testing. In addition, the length of the trial recordings influences the reliability estimates with longer recordings associated with higher reliability. A duration of up to 120 seconds has been recommended to reduce measurement error.[32] We used a sampling duration of 30 seconds to match the abilities of older adults, who may not have tolerated standing for 120 seconds. Nevertheless, the accelerometer can provide a reliable method to quantify balance measurements outside of a research setting given the portability and the low-cost features associated with it.

Strength Measures

The strength was consistent with reference values from adults 70-79 years old that were obtained using a hand-held dynamometer (HHD).[249–251] Our results indicated excellent test-retest reliability (ICC > 0.75) for all lower extremity muscle strength groups. In addition, reliability from averaging three consecutive trials, and single trial showed excellent test-retest reliability indicating that a measurement from single trial would be enough to obtain an adequate reliability in strength measurements. Therefore, the uniaxial load cell appears to provide a reliable and inexpensive measure of muscle strength.

Validity

Body sway measured with the accelerometer increased as the conditions became more challenging, thus demonstrating face validity of the accelerometer measurements. When somatosensory cues were reduced by using a foam pad, the older adults generated greater body sway compared with standing on firm surface. Moreover, during conditions where visual inputs were absent, body sway increased as compared to eyes open conditions. The current findings are consistent with previous research using similar technology.[34,37,201,240] Moreover, our results showed that the AP NPL during the eyes closed on foam condition was greater than the sway of healthy older adults mean age 47 years in a previous study that used a similar accelerometer, which further validates the measurements.[204] Similar results were reported in a different study on healthy older adults aged 66–85 for NPL for AP sway during the eyes closed on foam condition.[42]

The Spearman correlation results showed a significant correlation in 17/24 of the balance parameters with the total SPPB score, and in 22 of the 24 of the correlations with the balance component of the SPPB, indicating convergent validity. To the best of our knowledge this is the first study that examined the correlation between balance accelerometry and the SPPB. Among all the included balance parameters, the highest correlation coefficients between sway measures and the balance component of the SPPB were the RMS sway in the ML direction during standing in semi-tandem and tandem stances (rho=0.43 and 0.44, respectively). A simple explanation for this finding is that the semi-tandem and tandem balance conditions used for the accelerometer test mirrors the SPPB balance subtest. Previous studies showed similar results when comparing center of pressure measures using a force platform with clinical-based measures such as the SPPB.[205,206] However, the moderate correlation indicates that different aspects of balance are being measured by the accelerometer-based measurements.

The GES was significantly correlated with 15/24 of the sway measures. The highest value of correlation coefficients among the sway measures occurred in the foam, eyes open condition, and semi-tandem and tandem stances. These results indicate that individuals with greater sway had less confidence in their walking during everyday activities. Although, the correlation coefficients were significant, the strength of the relationship between the GES and sway measures was weak. This weak relationship could be explained by that the GES represents a person's rating of their own confidence performing different walking-related tasks, whereas the balance accelerometry captures balance performance in standing only. A study that used another self-efficacy scale, such as the Activities-specific Balance Confidence (ABC) scale, which was highly correlated with the GES, showed a similar correlation between postural sway and the ABC scale.[207]

The correlation with the 6MWT, which is more an assessment of mobility than balance was not as strong, reflecting other contributions to the 6MWT performance, such as lower-limb strength, simple reaction time, postural sway, and balance.[252] The correlation between measures of static balance and repeated chair stands time has been supported by Lord et al[243] who found a significant but weak relationship between the two measurements. Standing from a chair is a multidimensional task demanding a dynamic transfer of the center of mass and the ability to stabilize the center of mass within base of support. In addition, it requires enough lower extremity strength to be able to rise from a chair smoothly. These findings suggest that the COM outcomes and performance-based clinical tests examine different components of standing balance control.

Lower extremity strength measurements in this study had the highest correlation with repeated chair stands time, reinforcing the repeated chair stands test as a measure of lower limb strength. However, the correlation in this study (rho = -0.33 to -0.38) was lower than findings from previous studies that lower extremity strength explained about 40-48% of the variance in repeated chair stands performance.[208,243,253] In these previous studies, muscle strength groups were normalized for factors such as age, weight, and height, and that could explain the higher correlation. The plantarflexors showed the strongest correlation with repeated chair stands time among the included muscle groups (rho= -0.38), which is consistent with a previous finding[208] due to its important contribution in stabilizing the body in the upright standing position during each chair rise. A stronger correlation was found between leg strength and repeated chair stands time in studies where they combined all lower extremity strength tests together, and normalized the strength to body height and mass.[208] The strength of the relationship suggests that the repeated chair stands test is a multicomponent task requiring other factors such as balance, sensorimotor, and psychological factors.[243]

Both knee extensors and hip abductors but not ankle plantarflexors had a significant but weak correlation with the time to complete the F8WT. The correlation was higher in stroke survivors and patients with total knee arthroplasty, in which researchers found a moderate correlation (r= -0.46 for knee extensors and -0.67 for hip abductors) between the F8WT and strength measures.[254,255] In agreement with previous findings[256,257] we found a correlation of 0.24 between gait speed and knee extension strength, and a correlation of 0.22 for hip abduction strength. Giving the relationship of muscle strength to gait performance is modest at best.[54] The type of relationship between gait speed and lower extremity strength has been demonstrated to be a non-linear relationship meaning some physiological changes such as age-related loss of muscle mass may have more effects on gait speed in weak older adults than in healthy older adults.[258]

Minimal Clinically Important Difference

Knowledge about the MCID for balance accelerometry measurements and lower extremity muscle strength could help to promote the use of these devices in clinics; help clinicians to interpret the change that is important to subjects, and help researchers in evaluating the clinical significance of an intervention. However, there is no consensus on the best method to determine the MCID, and it has been recommended to estimate the MCID based on multiple approaches to obtain a range of values, as we did in the present study.[211] To the best of our knowledge there are no published studies that estimated the MCID using accelerometers and a uniaxial load cell device. The distribution-based methods for balance measurements were quite consistent across the measurements that had higher reliability; i.e. the MCID values increased as the balance condition became more difficult.

An advantage of using a distribution-based approach is the ability to account for change beyond measurement random variation. However, a big drawback of using this approach is it doesn't address the patients' or subjects' perspective of clinically important change.[211] The gold standard to determine the MCID is to use an external anchor since it takes into account the patient's perception of how much change is important. However, the main disadvantage of using an anchor-based approach is that the cut-off point to determine who improved or not is arbitrary.[211] Nevertheless, the ML NPL sway measures consistently showed the expected change in sway among the GRS subcategories. In the current study, for some of the balance conditions (i.e. the RMS measure), the anchor-based method did not display a clear discrimination between no change, small decline, and small improvement, because there was partial overlap across the change categories and their standard deviation was large relative to the point estimates. This is a common finding using the anchor-based method. Results from both distribution-based and anchor-based approaches didn't yield comparable results in most of the balance conditions. However, when trying to determine whether the change in score from the anchor-based method is not just a measurement error, the MCID must exceed the SEM.[259] In this study, all the included balance conditions had an MCID smaller than the SEM except for ML NPL sway when standing on foam with eyes closed. Therefore, interpretation of these findings should be interpreted with caution. As recommended by Guyatt et al.[212], in the anchor-based approach, the anchor should be at least moderately correlated with the instrument being examined, which was not the case in this study. There was no correlation between the balance GRS anchor and the change in sway measurements (data not shown). This assumption may limit the validity of the current MCID results. The anchor that was used in this study measures balance in more broad terms i.e. asking about balance in general, whereas the balance accelerometer was used to quantify postural sway during standing. Furthermore, the balance GRS questions were not specified to include sway as an indicator of good balance but were more about a subjective rating of balance in general, and older adults usually perceive balance as not having a fall, slip, or trip versus how much does he/she sway.[260] Therefore, a valid and appropriate external anchor is needed in order to estimate MCID accurately for static standing balance.

4.5 CONCLUSION

The dual-axis accelerometer and uniaxial-load cell provide a feasible, reliable, and inexpensive method for testing standing balance and lower extremity muscle strength, respectively in older adults. Among the included sway measures, the ML NPL measures demonstrated the highest test-retest reliability. Therefore, we recommend using these parameters to obtain a highly reliable measurement of sway in this population. Furthermore, the minimal clinically important difference values should be interpreted with caution given the drawbacks associated with the distribution-based and the anchor-based approaches utilized. Implementing the accelerometer and the uniaxial load cell technology may help investigators access understudied older populations living in independent living facilities, and will allow clinicians to examine objective measurements in real-life environments. Hopefully through the use of technology clinicians and therapists can prescribe interventions based on the subject's objectively identified balance deficits.

5.0 EFFECT OF TWO DIFFERENT GROUP EXERCISE INTERVENTIONS ON STANDING BALANCE AND LOWER EXTREMITY STRENGTH IN INDEPENDENT LIVING OLDER ADULTS

5.1 INTRODUCTION

Falls are a major public health problem facing older adults.[7] In people over 65 years, more than one-third of community-dwelling adults fall each year, and half will experience recurrent falls.[7] Falls have been associated with high rates of morbidity, reduced function, decreased quality of life, and premature nursing home and hospital admissions. About 20-30% of people who fall suffer injuries that lead to decreased mobility that restricts subsequent independence.[7,9,10]

Normal aging is related to a decline in many body systems including cardiovascular, sensation, musculoskeletal, and cognitive function, all of which have been associated with increased risk of falling.[14–16] It is well documented that aging itself also is associated with a decrease in muscle strength, balance, and functional mobility.[17] Older adults with walking dysfunction are at a high risk of greater ADL dependency.[261] Maintaining mobility is important for active aging and in preserving community independence; it is also related to better health status and quality of life.[18] Preserving postural stability is also imperative for elderly people to perform activities of daily living safely and independently within their society and thereby avoid falls.[19] Lower-extremity muscle weakness and balance impairment both have been related to mobility limitations and falls in older adults.[7,20]

The risk of falls can be altered by lifestyle changes, such as exercise and physical activity.[21,22] Therefore, implementing well-designed exercise interventions to improve mobility and balance function is necessary. Various exercise interventions have been developed and are intended to improve mobility and motor function in community-dwelling older adults.[23] However, each of these interventions is different in design, methodologies, and approach. Exercise interventions that aim to enhance postural control and mobility have consisted of strengthening and multidimensional exercises, concentrating on addressing the impairment of the involved systems (i.e. musculoskeletal or sensory).[24,25] Progressive resistance training programs for a period of 10 to 40 weeks have shown to lead to improvements in lower extremity muscle strength.[21,262] However, these improvements do not necessarily transfer to gains in balance, mobility or walking function.[263]

A contemporary training concept to improve walking and mobility focuses on task-oriented training through implementing motor learning approaches, in which individuals practice walking-related tasks. A number of studies that have investigated task-oriented walking exercise programs have indicated an improvement in walking outcomes in people with stroke.[26] A new task-oriented motor learning group-based exercise has been developed called *On the Move* (OTM), which aims to improve walking and promote independence in older adults by incorporating timing and coordination components. Preliminary data have shown a significant improvement in walking and mobility measures in people who received the OTM exercise program compared to a standard group exercise program.[264] The OTM program includes different walking and stepping exercises that may encourage lower extremity muscles to coordinate activation in order to swing, load, and unload the stepping limb. It has not been investigated if the OTM program affects some of the contributing factors related to fall risk. Therefore, the main purpose of the study is to determine the effect of the OTM program on standing balance performance and lower extremity muscle strength in residents of independent living facilities.

The OTM program was compared with a standard exercise program which focuses more on increasing the physiological capacity in body systems such as strengthening lower extremity muscles used in walking and maintaining balance. Although the lack of task-specific exercises in the standard exercise program may limit the amount of improvement in walking function, we wanted to determine how much effect it will have on standing balance and lower extremity strength. The standard exercise program also includes stretching exercises that are designed to increase joint range of motion and lower extremity muscle length to improve posture for walking and standing balance. Endurance exercises increase the delivery and exchange of oxygen to lower extremity muscles in order to sustain repeated muscle contractions required for prolonged walking.

5.2 METHODS

5.2.1 Study Design

This study was an ancillary study to a cluster randomized single-blind clinical trial that examined the effects of a standard group exercise program and a novel "*On the Move*" (OTM) group exercise on function, disability, and mobility in independent living older adults. This ancillary study was designed to determine the effects of these two different interventions on standing balance and lower-extremity strength in independent living older adults. The parent study involved two intervention groups, including the OTM exercise group and standard exercise group. As shown in **Figure 5.1**, facilities were randomly allocated to either the OTM exercise group or standard exercise group (STD) and then after the first baseline testing (BL-1), subjects in both intervention arms were again randomly assigned to either the wait list control group or immediate exercise groups (i.e. OTM or STD). For each intervention, subjects who were assigned to immediate exercise groups started the exercise intervention after BL-1, and subjects who were in the wait list control group had a 12-week period before starting the intervention. The outcome measurements were taken at two time points for subjects who started exercise immediately i.e. baseline (BL-1) and post-intervention (POST), and at three time points for those who were in the wait list control group i.e. before the waiting period (BL-1) and before (BL-2) and after the exercise intervention (POST).

Exercise leaders who had training and experience in administering exercise programs, such as physical therapists or physical therapist assistants, delivered the first 12 weeks of the immediate OTM and standard exercise interventions. In the original study design, facility staff activity personnel (i.e. staff employed by the facilities) were to be trained by the exercise leader to deliver the exercise program for the wait list exercise groups during the second 12-week period. However, in some facilities where a staff activity employee was not available for recruitment, an exercise leader delivered the program instead. As a result, there were four groups that were studied: 1) OTM group who received immediate (I) exercise that was led by an exercise leader (L) (OTM-IL, n=28); 2) STD group who received immediate exercise that was led by an exercise leader (STD-IL, n=33); 3) STD group who were on a 12-week wait list (W) and then received exercise that was led by facility staff (S) activity personnel (STD-WS, n=25); and 4) Wait list control group who was assigned to a 12-week waiting period (Wait list, n=46). The number of subjects in the OTM group who were on a 12-week wait list and then received exercise that was led by facility staff activity personnel (OTM-WS, n=12) was small, and thus removed from the main analysis.

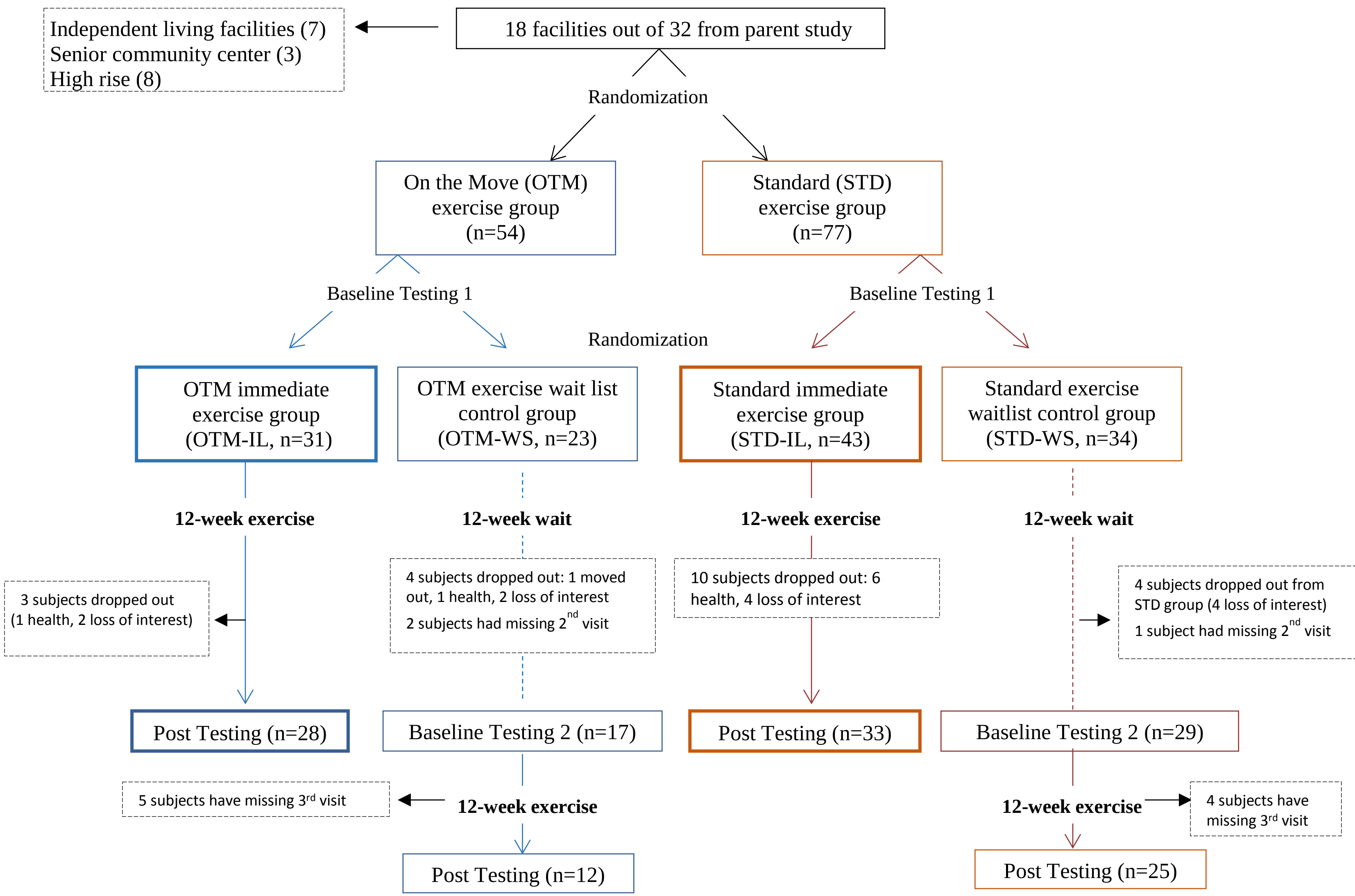

Figure 5.1: Study design and subjects flow to compare the effects of the *"On the Move"* versus the standard exercise program. The 32 facilities were the total number from the parent study, from which 18 facilities were used for this ancillary study.

5.2.2 Setting and Participants

A convenience sample of 131 people were recruited from 18 different sites (7 independent living facilities, 3 senior community centers, and 8 senior apartment buildings (high rises)) within the University of Pittsburgh Medical Center senior communities. The investigators of the parent OTM study informed the subjects about the current study. If the subject expressed his/her interest, the principal investigator of the current study, who was blinded to study groups, would then meet the subject and explain the study to him/her, including the overall purpose of the study, the study procedures, number of visits, and the potential benefits and risks of participating in the study. If the subject was willing to proceed, the principal investigator obtained informed consent, as approved by the University of Pittsburgh Institutional Review Board (IRB). This study took place from April 2014 to May 2016.

5.2.3 Inclusion/Exclusion Criteria

Inclusion and exclusion criteria followed that in the main study. The inclusion criteria were: (1) 65 years of age or older; (2) a resident of a University of Pittsburgh Medical Center (UPMC) independent living facility (ILF), high rise apartment, or senior community center; (3) ability to ambulate independently within the household with or without a straight cane; and (4) gait speed greater than or equal to 0.60 m/s. Subjects were excluded if they had one or more of the following exclusion criteria: (1) non-English speaking; (2) impaired cognition, which is defined as the inability to follow two-step commands or understand the informed consent process; (3)

plans to leave the area for an extended period of time over the next four months; (4) a progressive neuromuscular disorder such as Parkinson disease or multiple sclerosis; (5) any acute illness or medical condition that was not stable; and (6) inappropriate response to the Six Minute Walk Test (i.e. exercise heart rate ≥ 120 bpm, exercise systolic BP ≥ 220 or drop in SPB >10 mmHg, or drop in diastolic BP ≥ 110 mmHg).

5.2.4 Intervention Programs

Overview

The two exercise interventions were conducted twice a week for 12 weeks and each session lasted for 50 minutes. Instructors for both interventions were following a standardized protocol that described each activity and gave guidelines for progression based on subjects' performance. Both intervention arms included a brief warm-up period at the beginning of the exercise to prepare the musculoskeletal and cardiopulmonary systems for exercise, and a cool-down period at the end of the exercise session to return the body to the resting state. Also, both protocols included lower extremity strengthening exercises that aimed to increase muscular strength. They were conducted in both sitting and standing and included seated marching, seated hip abduction, and repeated chair rises. Exercises were progressed throughout the program by altering the speed, amplitude, or accuracy of performance.

5.2.4.1 On the Move exercise program

The *On the Move (OTM)* exercise program is a 50-minute exercise program that aimed to promote skill in walking acquisition based on principles of motor learning. The operationally defined program contained warm-up exercises (5 minutes), stepping and walking exercises (20-30 minutes), strengthening exercises (10 minutes) and cool-down exercises (5 minutes). The stepping and walking patterns were goal-oriented and designed to promote the appropriate timing and coordination of stepping during walking by enhancing proper weight-shifting during stepping, coordinating activation between hip abductors and adductors to facilitate the load/unload mechanism, and by practicing coordination of the legs and trunk during walking. The stepping patterns included an extensive progression of stepping sequences. The progression was made by altering the speed, amplitude, or accuracy of performance. For example, subjects started the stepping patterns with self-paced step forward and across, and progressed by increasing stepping speed, alternating sides and the direction of stepping. The walking patterns consisted of walking in a variety of pre-determined patterns using cones to create different walking patterns. Similarly, walking patterns were progressed by altering the speed, amplitude (e.g. narrowing the path width), or accuracy of performance. The progression included more complex walking patterns such as bouncing or carrying a ball while walking, or walking past other walkers. The majority of the program was conducted in standing (40 minutes) with only a small portion conducted in sitting (10 minutes). The exercise sessions were twice a week for 12 weeks and were delivered by exercise leaders.

5.2.4.2 Standard Exercise program

The standard group exercise program was based on exercise programs that were currently being conducted at the facilities (i.e. standard of care). The operationally defined program contained warm-up exercises (5 minutes), cardiovascular exercises (20 minutes), strengthening exercises (15-20 minutes) and cool-down exercises (10 minutes). The warm-up and cool-down contained range of motion exercises and stretches for the lower extremities and trunk. The cardiovascular exercises consisted of arm and leg movements causing the heart rate to increase. The strengthening exercises were conducted in both sitting and supported standing positions and included seated marching, seated hip abduction, and repeated chair stands that targeted the lower extremity muscles. The majority of the program was conducted in sitting. Similar to the OTM, a specific music playlist was designed to be played during standard exercise classes. The exercise sessions were twice a week for 12 weeks and were delivered by exercise leaders and activity staff personnel.

5.2.4.3 Wait list control group

The reason for adding a wait list group in the original study was to examine the sustainability of the program. Although staff activity personnel employed by the facilities were intended to deliver the interventions for the wait list group, in some facilities a staff activity employee was not available and an exercise leader delivered the exercise instead. After the waiting period, subjects received either the OTM exercise or standard exercise intervention based on what intervention arms they were allocated to. Subjects on the wait list were asked to continue with their normal daily routine during the waiting period.

5.3 OUTCOMES

The main outcome measures were the postural sway measured by the accelerometer during the modified Clinical Test of Sensory Interaction in Balance (mCTSIB),[228] and the Short Physical

Performance Battery (SPPB),[229] and the lower extremity strength measurements. Both were measured at baseline and after 12 weeks for all subjects, and after 24 weeks for subjects who were in the wait list groups.

5.3.1 Instrumentation

5.3.1.1 Balance Accelerometry (BA)

The accelerometer was developed as a part of the National Institutes of Health (NIH) Toolbox project as a balance measurement.[42] The BA system consists of a dual axis accelerometer (ADXL213AE, with range of ±1.2 g and resolution of 1mg; Analog Devices, Inc., Norwood, MA) oriented to record mediolateral and anteroposterior acceleration of the body. The acceleration is transmitted via a Bluetooth transmitter to a laptop computer at 50 Hz and with 16-bit accuracy. The system was affixed to subjects' backs at the level of the iliac crest using Velcro and a gait belt. A custom written Labview program was used to acquire the data. The foam surface that was used in the testing consisted of an AIREX® Balance Pad (Alcan Airex AG, Switzerland), and the foam pad thickness was 6 cm. The acceleration data were visually inspected and the abrupt spike-like noise that was caused by sudden movement of the accelerometer was removed. The first and last five seconds of the recording were not included in the analysis in order to eliminate transient effects.[240] Using a custom written Matlab program, the acceleration data were lowpass filtered using a 4th order Butterworth filter with a cutoff frequency of 2 Hz. The cutoff frequency calculation was based on the Nyquist sampling theorem, which states that sampling frequency should be at a frequency greater than twice as high as the highest frequency contained in the signal.[241] A cutoff frequency of 2 Hz is sufficient to capture the sway signal, since postural sway during quiet standing is typically restricted to low frequencies (<1 Hz).[242]

The Root Mean Square (RMS) and the Normalized Path Length (NPL) for both directions, the anteroposterior acceleration (AP) and mediolateral acceleration (ML) were calculated; a higher value indicates more sway. The RMS and NPL were calculated as follows:

$$RMS = \sqrt{\frac{\left(\sum_{j=1}^{N-1} p_j\right)^2}{N}} \quad \text{mG} \quad (1)$$

$$NPL = \frac{1}{t}\sum_{j=1}^{N-1} \left|p_{j+1} - p_j\right| \quad \text{mG/s} \quad (2)$$

where t is the time duration, N is the number of time samples, and p_j is the acceleration data at time sample j. The mG stands for milli-Gravitational acceleration, where 1 mG = 0.0098 m/s^2 and mG/s is the milli-Gravitational acceleration divided by the time duration in seconds.

5.3.1.2 Uni-axial load cell device:

A uni-axial load cell (Measurement Specialties XTC Series) was used to measure lower extremity strength. The load cell has a maximum capacity of 2225 N. The load cell was connected to an amplifier that displayed the instantaneous and maximum force exerted on the load cell. The load cell is arranged in series with straps (two cuffs) that fit around the limb on one end and a stable object on the other end.

5.3.2 Procedure

Standing Balance Test:

The BA protocol was composed of six different conditions that were based on two tests. The first test was the modified Clinical Test of Sensory Interaction in Balance (mCTSIB),[228] which was designed to examine the utilization of the three important sensory systems (i.e. vision, somatosensory, and vestibular) for postural stability. The second test was the instrumented Short Physical Performance Battery (SPPB),[229] which measures different aspects of functional mobility and the ability to stand with a narrow base of support. The order of testing was presented to each subject, from easier to more challenging conditions, as follows: (1) Standing with feet together on a firm surface with eyes open (Firm-EO); (2) standing with feet together on a firm surface with eyes closed (Firm-EC); (3) standing with feet together on a foam surface with eyes open (FOAM-EO); (4) standing with feet together on a foam surface with eyes closed (FOAM-EC); (5) standing with a semi-tandem (one foot halfway in front of the other) stance on a firm surface with eyes open; and (6) standing with a tandem stance on a firm surface with eyes open. For the semi-tandem and tandem stance conditions, the subjects placed their feet according to their preference.[230] During these conditions, subjects stood 0.5-meters from the wall with their shoes on and their arms were crossed in front of their chests. In order to standardize shoe-wear, subjects were asked to wear their customary walking shoes (i.e. no high heels, no sandals) for the testing. Each condition was performed for 30 seconds. The subjects were allowed to perform each condition two times. If the subjects failed to perform both trials of a condition, they would continue onto the next condition, and the investigator would document that the subjects weren’t able to complete the task.

Lower Extremity Strength Testing:

Strength measurements included three maximum voluntary isometric contractions (MVIC) for three different muscle groups. All of the testing was done in sitting position. Testing positions have been adopted from studies that have used isokinetic and isometric dynamometers; details about the device positions for each muscle group are summarized in **Table 4.1**. To standardize which leg was tested, the dominant foot was determine by asking the subjects about the foot that they would use to kick a ball for the knee extension and ankle plantarflexion.[231] Hip abductor strength was tested bilaterally due to the subject positioning. The tone and words of encouragement used by the examiner were standardized. During each trial, the subject increased force up to a maximum over the course of five seconds. Thirty seconds of rest was provided between trials. The peak value was recorded from the amplifier. The average of the three trials was used in the data analysis. All of the measurements were taken by a physical therapist.

5.3.3 Statistical Analysis

Data were analyzed using both SPSS version 22.0 (IBM, Armonk, NY) and SAS software version 9.4 (SAS Institute, Inc., Cary, NC). Subject demographics, clinical characteristics, and baseline measurements of balance and strength were compared using one-way analysis of variance for continuous variables and a chi-square test for categorical variables. An independent t-test and a chi-squared test were used to compare baseline characteristics for participants completing the study to those lost to follow-up. A Shapiro-Wilk test revealed a non-normal distribution of the acceleration and the strength data; hence the Wilcoxon signed-rank test was used to compare performance between time points for each group. A linear mixed model (PROC MIXED) was used to examine balance and strength performance across the exercise groups with the change across time points in each outcome as the dependent variable; treatment group as a fixed effect; sites and subjects as random effects; and pre-intervention score, and any other demographic variables found to be different at baseline between groups, as covariates. Then several ESTIMATE statements in the PROC MIXED procedure were constructed in order to examine the following hypotheses. A significance level of α=0.05 was used for all analyses.

There were two primary hypotheses related to examination of the effect of the OTM intervention. In addition, there were three secondary hypotheses related to comparisons involving the standard exercise groups.

Primary hypotheses:

Hypothesis 2.1: OTM-IL vs. STD-IL

There will be a significant difference in the magnitude of change in balance performance (improvement), but not in the muscle strength, from the baseline assessment (BL-1) to the 12-week post-intervention assessment, between the OTM immediate exercise group and the immediate standard exercise group (STD).

OTM-IL: BL-1 $\xrightarrow{\text{12-week OTM exercise program}}$ Post-intervention

STD-IL: BL-1 $\xrightarrow{\text{12-week standard exercise program}}$ Post-intervention

Hypothesis 2.2: OTM-IL vs. All Wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the OTM immediate exercise group compared to the combined wait list control groups.

OTM-IL: BL-1 $\xrightarrow{\text{12-week OTM exercise program}}$ Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

Secondary hypotheses:

Hypothesis 2.3: STD-IL vs. All Wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by an exercise leader, compared to wait list control group.

STD-IL: BL-1 12-week standard exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

Hypothesis 2.4: STD-IL vs. STD-WS

There will be a significant difference in the magnitude of change in balance performance and muscle strength from the baseline assessment to the 12-week post-intervention assessment, between the standard exercise group when delivered by an exercise leader and the standard exercise group when delivered by staff activity personnel.

STD-IL: BL-1 12-week standard exercise program Post-intervention

STD-WS: BL-2 12-week standard exercise program Post-intervention

Hypothesis 2.5: STD-WS vs. All wait list

There will be a significant difference in the magnitude of change in balance performance and muscle strength, from the baseline assessment to the 12-week post-intervention assessment, for the standard exercise group when delivered by staff activity personnel, compared to wait list control group. For this comparison, there were some subjects who participated in both groups, and that was accounted for in the statistical analysis.

STD-WS: BL-2 12-week standard exercise program Post-intervention

All Wait list: BL-1 12-week waiting period BL-2

5.4 RESULTS

A total of 131 subjects were recruited to participate in this study. Of these, 24 subjects dropped out after the first baseline testing for various reasons explained in **Figure 5.1**. A total of 107 subjects who completed baseline and post-intervention testing were included in the main analysis. **Table 5.1** shows that subjects across the four groups were similar on most baseline characteristics. The OTM-IL had less subjects who had at least some college education compared with STD-IL and STD-WS groups ($p < 0.012$). In addition, the OTM-IL had a higher prevalence of diabetes compared with STD-WS ($p < 0.002$). To avoid the risk of confounding the between-groups comparisons by any differences at baseline, the education and diabetes variables were included as covariates in the model. Subjects who completed baseline and post-intervention assessment (n = 107; 82%) were similar to those who had withdrawn after the first baseline testing (n = 24; 18%) (**Table 5.2**). Adherence to the exercise programs over the 12 weeks was defined as attending at least 80 % of the total sessions, (20+ sessions out of 24). About 64% of participants in the OTM-IL exercise group, 78% of the STD-IL, and 72% of the STD-WS exercise groups attended 20 or more exercise sessions. The wait list for the OTM and for the standard exercise group was combined to be used in the main analysis as one wait list control group. **Table 5.3** shows that demographics and clinical characteristics for subjects in the current study were similar to the parent study descriptively.

Balance accelerometry:

For balance accelerometry outcomes, **Table 5.4** compares the within-group mean change between the BL-1 and post-intervention assessment, or between BL-1 and BL-2 for the wait list control group. The OTM immediate exercise group (who were taught by an exercise leader, OTM-IL) consistently showed a significant reduction in NPL sway in both the AP and ML directions for most balance conditions ($p<0.05$), except standing on level surface with eyes open. The standard immediate exercise group who were taught by an exercise leader (STD-IL) showed a significant decrease only in the AP direction when standing on foam with eyes closed ($p<0.05$). Subjects in the standard exercise group who received exercise by activity staff personnel after being on the waitlist (STD-WS) had a significant decrease in NPL sway in both the AP and ML directions when standing on foam with eyes closed and during tandem stance. They also had a reduction in AP sway during standing on firm and foam surfaces with eyes open and semi-tandem stance. Finally, participants who were on the waitlist showed a significant decrease in NPL sway in the ML axis when standing on a compliant surface with eyes closed ($p<0.05$). However, there was a significant increase in the AP direction during the level, eyes open condition. Due to the higher reliability that was associated with the NPL sway measures, only the

NPL measures were reported in this chapter. However, the RMS sway yielded similar results as the NPL parameter (See Appendix A.1).

Table 5.5 summarizes the difference in mean change between-groups for the balance accelerometry conditions after adjusting for the baseline values, age, gender, and covariates at baseline such as education level, and diabetes. Although the OTM-IL group consistently showed greater reduction in sway compared with the STD-IL group, the mean change was not significant. Generally, both the OTM and standard exercise groups showed a significant decrease in postural sway as compared to waitlist control group. A significant mean decrease in AP NPL sway for the OTM-IL compared to waitlist control group occurred on three of the six test conditions, and during tandem and semi-tandem stances in the ML axis ($p < 0.001$) (**Table 5.5**). In addition, STD-IL showed a significant reduction in sway as compared to waitlist control group, in the AP NPL sway when standing on firm surface with eyes open, standing on foam with eyes open ($p < 0.001$). In a comparison between the two delivery modes for the standard exercise arm, the STD-WS group had a greater reduction compared with the STD-IL group, but only the NPL sway in the ML axis during tandem stance showed a significant difference between the two groups. Finally, when comparing STD-WS to the waitlist control group, the STD-WS exercise group showed a significant decrease in the AP direction for the NPL sway when standing on the firm surface with eyes open and standing on the foam surface with eyes open and closed. Also, a significant decrease in ML sway during tandem and semi-tandem stances was shown ($p < 0.001$).

Next we compared the change in sway with the minimal clinically important difference (MCID), using the standard error of the measurement (SEM) from the reliability subsample (**Table 5.6**). For the OTM-IL group, only the change in ML NPL sway during standing on foam surface with eyes closed and semi-tandem was greater than the SEM. For the STD-WS group, the change in the AP and ML NPL sway during standing on foam surface with eyes closed, and tandem stance in both AP and ML directions was higher than the SEM. However, all the statistically significant changes in NPL sway across groups was larger than the small improvement cutoff score resulting from the anchor-based approach.

There was no significant difference in change in ML NPL postural sway after the exercise intervention across subjects based upon presence of a chronic condition, except between subjects who had a joint replacement compared to those who had not when standing on foam surface with eyes closed and during semi-tandem stance in the M-L axis. Also, there was a difference between those who had osteoarthritis vs. those who had not for the group during semi-tandem stance in the ML direction **(Table 5.7).**

Muscle strength:

The within-group mean change in muscle strength between the baseline and post-intervention assessment is presented in **Table 5.8**. The OTM-IL and STD-IL groups had an increase in the knee extension and hip abduction strength that ranged from 2.9% to 10.5%; however, for the ankle PF there was a slight decrease −0.6% −2.4% (**Figure 5.2)**. The waitlist control group showed a clear decrease in muscle strength as compared to the two exercise groups ranging from −10.7% to −13.2%. After adjusting for the baseline values and potential covariates including height, the linear mixed model output showed no significant mean change between OTM-IL- and STD-IL for all the three muscle groups, although the intervention favored the STD-IL group. In addition, there was no significant change between STD-IL and STD-WS across muscle groups. However, when comparing exercise groups to the waitlist control group, a significant mean change was found between groups (**Table 5.9).**

Table 5.1: Baseline characteristics of participants assigned to exercise groups

Characteristics	OTM-IL (n=28)	OTM-WS (n=17)	STD-IL (n=33)	STD-WS (n=29)	p
Age, mean ± SD	78.1 (8.0)	79.1 (8.2)	81.2 (7.9)	82.0 (5.4)	0.193
Female, n (%)	25 (89.2)	15 (88.2)	29 (87.8)	21 (72.4)	0.251
Race					
White n (%)	25 (89.2)	17 (100)	25 (75.7)	21 (72.4)	0.058
Married, n (%)	5 (17.8)	6 (35.2)	3 (9.0)	8 (27.5)	0.121
Education,[a] n (%)	8 (28.5)	10 (58.8)	20 (60.6)	20 (68.9)	**0.014**
Chronic conditions					
Cardiac, n (%)	4 (14.2)	1 (5.8)	7 (21.2)	5 (17.2)	0.559
Neuro, n (%)	1 (3.5)	0	5 (15.1)	2 (6.8)	0.186
Musculoskeletal, n (%)	27 (96.4)	15 (88.2)	25 (75.7)	26 (89.6)	0.109
Visual/Hearing, n (%)	21 (75)	14 (82.3)	25 (75.7)	25 (86.2)	0.679
Diabetes, n (%)	11 (39.2)	2 (11.7)	7 (21.2)	1 (3.4)	**0.006**
Cancer, n (%)	5 (17.8)	1 (5.8)	7 (21.2)	8 (27.5)	0.346
Lung, n (%)	6 (21.4)	6 (35.2)	7 (21.2)	11 (37.9)	0.359
Gait speed m/s, mean ± SD	0.88 (0.20)	0.98 (0.13)	0.93 (0.19)	0.95 (0.21)	0.339
SPPB (Total) (SD)	9.4 (1.50)	10.2 (1.33)	9.30 (1.87)	9.82 (1.81)	0.290
Chair-rise test, s (SD)	15.1(3.76)	12.9 (2.67)	15.8 (5.72)	14.1 (5.25)	0.201
Height	1.60 (0.12)	1.59 (0.09)	1.62 (0.10)	1.65 (0.10)	0.421

SPPB: short physical performance battery.

[a]: was defined as attended at least some college.

Bold font indicates significant at p<0.05.

Table 5.2: Baseline characteristics of participants who dropped out after baseline and non-dropouts at all time points

Characteristics	Participants who completed both baseline and post-intervention assessments (n=107)	Participants who completed only the baseline assessment (n=24)	p
Age, mean ± SD	80.4 (7.4)	80.1 (8.9)	0.849
Female, n (%)	90 (84.1)	21 (87.5)	0.447
Race			
White n (%)	88 (82.2)	20 (83.3)	0.598
Married, n (%)	22 (20.5)	5 (20.8)	0.602
Education, [a] n (%)	58 (54.2)	12 (50)	0.443
Chronic conditions			
Cardiac, n (%)	17 (15.8)	7 (29.1)	0.101
Neuro, n (%)	8 (7.4)	3 (12.5)	0.117
Musculoskeletal, n (%)	93 (86.9)	22 (91.6)	0.405
Visual/Hearing, n (%)	85 (79.4)	19 (79.1)	0.190
Diabetes, n (%)	21 (19.6)	3 (12.5)	0.312
Cancer, n (%)	21 (19.6)	7 (29.1)	0.221
Lung, n (%)	30 (28)	11 (45.8)	0.075
Gait speed (m/s)	0.93 (0.19)	0.87 (0.19)	0.146

[a] was defined as attended at least some college.

Table 5.3: Comparison of baseline characteristics between participants of the current study and the parent study

Characteristics	Current study (n=131)	Parent study (n=424)
Age, years	80.3 (7.7)	80.4 (7.8)
Female, n (%)	111 (84.7)	349 (82.3)
Race		
White n (%)	110 (83.9)	352 (83)
Married, n (%)	28 (21.3)	99 (23.3)
Graduate education, n (%)	70 (53.4)	18(50.9)
Chronic conditions		
Cardiac, n (%)	24 (18.3)	76 (17.9)
Musculoskeletal, n (%)	115 (87.7)	347 (81.8)
Visual/Hearing, n (%)	104 (79.3)	316 (74.5)
Diabetes, n (%)	24 (18.3)	84 (19.8)
Cancer, n (%)	28 (21.3)	84 (19.8)
Lung, n (%)	41 (31.2)	93 (21.9)
Gait speed, m/s (SD)	0.92 (0.19)	0.92 (0.20)
SPPB (Total) (SD)	9.4 (1.74)	9.4 (1.81)
GES score (SD)	75.3 (14.7)	75.2 (14.3)
Chair-rise test, s (SD)	15.2 (5.04)	15.4 (5.86)
6MWT, m (SD)	289.5 (78.6)	276.7 (89.5)
F8WT, s (SD)	10.2 (2.9)	10.4 (3.2)

Table 5.4: Pre- and Post-intervention change in balance performance (NPL) across groups. EO: Eyes Open, EC: Eyes Closed, AP: Antero-posterior, ML: Medio-lateral

Balance conditions (NPL)		OTM-IL (n=28)[a]		STD-IL (n= 33)[a]		STD-WS (n=25)[a]		Waitlist (n=46)	
		Change [b]	p [d]	Change [b]	p [d]	Change [b]	p [d]	Change [c]	p [e]
Level EO	AP	-0.40	0.973	-1.11	0.458	-1.43	**0.049**	1.28	**0.042**
	ML	-0.62	0.261	0.72	0.741	-1.79	0.061	0.62	0.195
Level EC	AP	-2.83	**0.009**	-1.24	0.979	-2.52	0.326	0.13	0.468
	ML	-2.43	**0.043**	0.04	0.448	-2.04	0.187	-1.39	0.152
Foam EO	AP	-5.56	**0.001**	-3.74	0.11	-4.66	**0.034**	0.95	0.294
	ML	-6.72	**0.001**	-2.08	0.48	-4.93	0.230	-1.01	0.364
Foam EC	AP	-7.49	**0.013**	-5.28	**0.015**	-11.12	**0.004**	-2.67	0.328
	ML	-14.29	**0.001**	-7.68	0.116	-8.85	**0.040**	-7.38	**0.005**
Semi-tandem	AP	-4.49	**0.043**	-2.08	0.195	-3.25	**0.035**	1.59	0.236
	ML	-5.94	**0.004**	0.10	0.782	-2.99	0.211	-0.06	0.604
Feet tandem	AP	-6.06	**0.001**	-2.06	0.172	-10.31	**0.002**	-1.07	0.609
	ML	-5.71	**0.012**	-2.83	0.852	-6.89	**0.002**	-1.60	0.6

[a] OTM-IL= On the Move immediate leader, STD-IL = Standard immediate leader, STD-WS=Standard waitlist staff

[b] Change in balance performance from baseline to post-intervention. Negative values denote improvement.

[c] Change in balance performance from baseline 1 to baseline 2. Negative values denote improvement.

[d] Wilcoxon-signed rank test of the difference from baseline to post-intervention across groups. Bold font indicates significant at p<0.05.

[e] Wilcoxon-signed rank test of the difference from baseline 1 to baseline 2.

Table 5.5: Adjusted mean change in balance performance between groups. EO: Eyes Open, EC: Eyes Closed, AP: Antero-posterior, ML: Medio-lateral

Balance Conditions		OTM-IL v. STD-IL [a]	OTM-IL v. Waitlist	STD-IL v. Waitlist	STD-IL v. STD-WS [a]	STD-WS v. Waitlist
		Estimate (SE) [b]	Estimate (SE) [b]	Estimate (SE) [b]	Estimate (SE) [b]	Estimate (SE) [b]
Level EO	AP-NPL	0.30 (1.33)	**-2.52 (1.29)**	**-2.83 (1.16)**	0.51 (1.34)	**-3.34 (1.25)**
	ML-NPL	-1.07 (1.17)	-1.00 (1.12)	0.07 (1)	2.28 (1.15)	-2.2 (1.14)
Level EC	AP-NPL	-1.98 (1.81)	-2.79 (1.72)	-0.81 (1.57)	0.58 (1.72)	-1.39 (1.95)
	ML-NPL	-2.48 (1.69)	-1.19 (1.58)	1.28 (1.39)	2.68 (1.59)	-1.40 (1.56)
Foam EO	AP-NPL	-3.00 (2.22)	**-6.8 (2.04)**	**-3.78 (1.83)**	3.03 (2.01)	**-6.82 (2.26)**
	ML-NPL	-2.98 (2.92)	-2.36 (2.52)	0.61 (2.14)	4.41 (2.32)	-3.79 (2.50)
Foam EC	AP-NPL	-4.02 (3.19)	**-7.24 (2.92)**	-3.21 (2.67)	8.64 (2.96)	**-11.8 (3.27)**
	ML-NPL	-3.44 (4.19)	-1.15 (3.71)	2.29 (3.26)	6.90 (3.61)	-4.61 (3.75)
Semi-tandem	AP-NPL	-0.94 (1.91)	-2.43 (1.67)	-1.48 (1.48)	2.53 (1.64)	-4.01 (1.63)
	ML-NPL	-4.18 (2.46)	**-6.69 (2.30)**	-2.49 (2.05)	3.88 (2.23)	**-6.37 (2.60)**
Feet tandem	AP-NPL	-4.90 (4.23)	-4.41 (4.01)	0.48 (3.62)	6.26 (3.95)	-5.77 (4.59)
	ML-NPL	-4.53 (3.85)	**-9.90 (3.71)**	-5.37 (3.39)	**10.17 (3.70)**	**-15.54 (4.29)**

[a] OTM-IL= On the Move immediate leader, STD-IL = Standard immediate leader, STD-WS=Standard wait staff

[b] Mean estimated group differences and standard error for changes in balance performance after adjusting for baseline values and other potential covariates. Bold font indicates significant at $p<0.05$

Table 5.6: Comparison between change in NPL sway and MCID values.

Balance conditions (NPL)		**OTM-IL**	**STD-IL**	**STD-WS**	**Waitlist**	**SEM**	**Small Improvement MCID**	**Small Decline MCID**
Level EO	AP	-0.40	-1.11	-1.43	1.28	3.11	− 1.21	0.26
	ML	-0.62	0.72	-1.79	0.62	3.39	− 0.07	0.07
Level EC	AP	-2.83	-1.24	-2.52	0.13	5.19	− 2.85	0.83
	ML	-2.43	0.04	-2.04	-1.39	3.98	− 1.43	0.47
Foam EO	AP	-5.56	-3.74	-4.66	0.95	5.76	− 1.51	1.00
	ML	-6.72	-2.08	-4.93	-1.01	7.22	− 0.39	6.11
Foam EC	AP	-7.49	-5.28	<u>**-11.12**</u>	-2.67	8.05	− 5.80	4.37
	ML	<u>**-14.29**</u>	-7.68	<u>**-8.85**</u>	-7.38	8.98	− 2.39	15.06
Semi-tandem	AP	-4.49	-2.08	-3.25	1.59	7.21	− 2.74	− 0.77
	ML	<u>**-5.94**</u>	0.10	-2.99	-0.06	4.96	− 0.59	1.11
Feet tandem	AP	-6.06	-2.06	<u>**-10.31**</u>	-1.07	8.67	− 2.45	− 2.34
	ML	-5.71	-2.83	<u>**-6.89**</u>	-1.60	6.11	− 0.56	4.97

Bold font indicates significant at p<0.05. SEM: standard error of measurement (n=131).
Underlined values indicate larger than the SEM

Table 5.7 Mean (SD) change in magnitude of ML NPL postural sway during three challenging balance conditions, as function of presence of a chronic condition. An independent t-test examined the effect of chronic medical conditions.

Chronic conditions	Foam EC (ML NPL)	Semi-tandem (ML NPL)	Feet tandem (ML NPL)
Diabetes, mean (SD)			
Yes	-5.6 (13.1)	-1.9 (5.7)	-3.4 (9.1)
No	-9.4 (19.9)	-2.4 (9.8)	-4.0 (13.9)
Joint-replacement, mean (SD)			
Yes	**-15.4 (21.7)**	**-6.5 (12.6)**	-8.0 (14.3)
No	**-6.4 (17.2)**	**-0.9 (7.3)**	-2.7 (12.4)
Osteoarthritis, mean (SD)			
Yes	-9.7 (19.6)	**-3.7 (9.4)**	-4.9 (11.1)
No	-5.7(15.9)	**-0.7 (7.4)**	-1.5 (16.4)
Falls, mean (SD)			
Yes	-14.2 (19.8)	-4.7 (10.9)	-6.6 (9.9)
No	-6.3 (17.7)	-1.4 (8.2)	-2.9 (13.9)

Bold font indicates significant at $p<0.05$.

Table 5.8:Baseline and Post-intervention muscle strength (Mean ± SD), and change in strength, across groups. BL-1: Baseline 1, BL-2: Baseline 2, Post: Post-intervention

Isometric action (N)	OTM-IL (n=28)[a]				STD-IL (n= 33)[a]			
	BL-1	Post	Change	P [b]	BL-1	Post	Change	P [b]
Hip Abductor	176 ± 61	188 ± 64	12	**0.01**	178 ± 78	192 ± 80	14	**<0.01**
Knee Extensor	197 ± 55	203 ± 66	6	0.41	190 ± 63	210 ± 79	20	**0.04**
Ankle Plantarflexor	216 ± 63	211 ± 69	-5	0.63	234 ± 96	232 ± 94	-2	0.90

Isometric action (N)	STD-WS (n=26)[a]				Waitlist (n=46)[a]			
	BL-1	Post	Change	P [b]	BL-1	BL-2	Change	P [c]
Hip Abductor	166 ± 54	190 ± 56	24	**<0.01**	199 ± 66	173 ± 60	-26	**<0.01**
Knee Extensor	173 ± 61	196 ± 66	23	**<0.01**	201 ± 64	180 ± 66	-21	**<0.01**
Ankle Plantarflexor	219 ± 74	233 ± 74	14	**0.03**	253 ± 91	219 ± 85	-34	**<0.01**

[a] OTM-IL= On the Move immediate leader, STD-IL = Standard immediate leader, STD-WS=Standard wait staff

[b] Wilcoxon-signed rank test of the difference from baseline to post-intervention across groups. Bold font indicate significant at p<0.05

[c] Wilcoxon-signed rank test of the difference from baseline 1 to baseline 2.

Table 5.9: Adjusted mean change in muscle strength between groups.

Isometric action (N)	OTM-IL v. STD-IL[a] Estimate (SE)[b]	OTM-IL v. Waitlist Estimate (SE)[b]	STD-IL v. Waitlist Estimate (SE)[b]	STD-IL v. STD-WS[a] Estimate (SE)[b]	STD-WS v. Wait Estimate (SE)[b]
Hip abductor	-2.5 (5.5)	**37.1 (5.2)**	**39.6 (5.0)**	-8.6 (5.9)	**48.2 (5.5)**
Knee extensor	-8.6 (12.3)	**26.0 (10.7)**	**34.6 (9.8)**	-4.9 (11.1)	**39.5 (10.6)**
Ankle Plantarflexor	-4.1 (13.8)	**26.1 (12.8)**	**30.2 (12.4)**	-2.8 (14.2)	**33.0 (12.0)**

[a] OTM-IL= On the Move immediate leader, STD-IL = Standard immediate leader, STD-WS=Standard wait staff

[b] Mean estimated group differences and standard error for changes in muscle strength after adjusting for baseline values and other potential covariates include height. Bold font indicates significant at $p<0.05$.

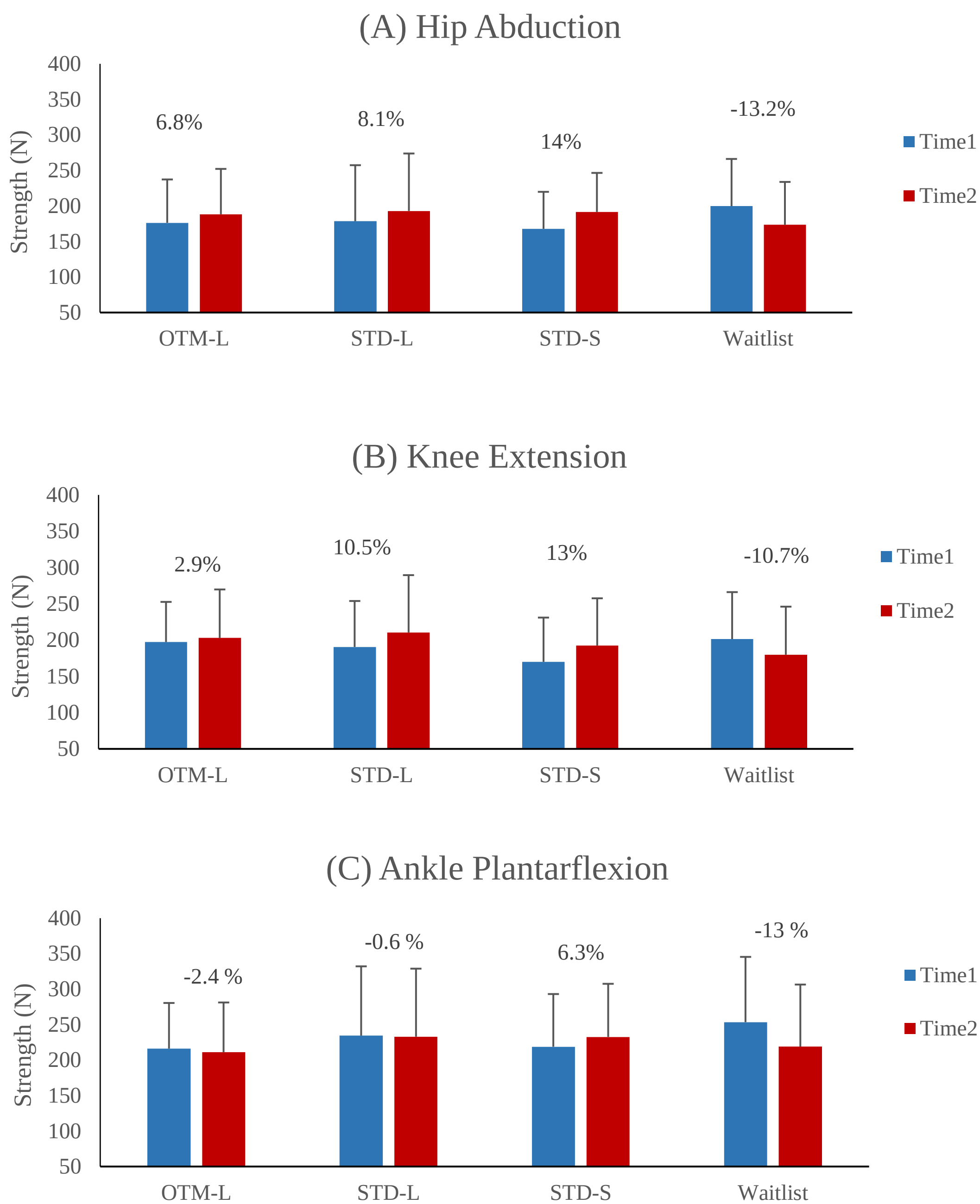

Figure 5.2: Percentage change in lower extremity muscle strength between baseline and postintervention for the exercise groups, and between baseline1 to baseline2 for the waitlist control group.

5.5 DISCUSSION

The primary goal of the current study was to examine the effect of the new task-oriented motor learning group-based exercise, the OTM exercise program, on standing static balance and lower extremity muscle strength in residents of independent living facilities. The magnitude of change in balance and strength performance was compared to that from a standard exercise program, and also to a waitlist control group. In addition, a comparison between the standard exercise group led by an exercise leader and the exercise group led by staff activity personnel was made. The main findings of this study was that a 12-week program of group-based exercise results in improvement in balance and muscle strength when compared to not receiving any exercise (i.e., the waitlist control group).

A decrease in the AP and ML sway was clear after the OTM exercise program when examining the within-group difference from baseline to post-intervention, across included balance conditions except standing on level surface with eyes open. These findings are in accordance with previous findings that suggest that postural stability shows no improvement in conditions that are not challenging to the postural control system.[265] This reduction was more prominent for the OTM-IL group compared with the standard exercise group. Although the OTM exercise program was originally designed to improve walking function, there appears to be carryover to standing balance. It is possible that some of the OTM exercises addressed balance components, such as weight-shifting by stepping, and walking in different pre-determined patterns. Improvements in AP and ML postural control may also be related to the stepping patterns, which occurred in both AP and ML directions. The stepping patterns facilitate the hip load-unload mechanism, which may have resulted in this improvement in ML neuromuscular control while standing.[69] Because neuromuscular control and coordination of inter-limb hip abductors/adductors, along with trunk movement control, are heavily involved in achieving lateral postural stability,[266] the relative improvement in ML sway is likely attributable to the repeated and progressive stepping patterns that challenge the lateral stability system.

The relative changes in sway in the OTM-IL group compared with the STD-IL group were in the hypothesized direction, but did not achieve statistical significance. Our results showed a trend for reduced sway after a 12-week program of group-based motor learning for the OTM-IL exercise group as compared with the STD-IL group in most of the included balance conditions, after adjusting for the baseline value and other covariates. The lack of a between-group difference indicates that a standard group exercise program focusing on seated resistance exercises may also have some benefit in improving standing balance in older adults. It is possible that a longer trial duration or a larger sample size would have further differentiated between the two groups. In addition, the adherence to the exercise program for the OTM-IL was 64%, which was lower than the adherence of 78% and 72% for the STD-IL and STD-WS groups, respectively. Therefore, our findings could underestimate the effectiveness of the OTM exercise program due to the lower adherence to the exercise intervention.

To validate these results by comparing both interventions (i.e., OTM-IL and STD-IL) to a waitlist control group, a clear trend of reduction was seen in sway in both AP and ML directions for the OTM-IL and only in the AP sway for the STD-IL. The improvement of standing balance in the exercise groups was significantly greater than that of the waitlist control group in some key balance conditions. For instance, a clear significant change was noted in NPL sway in the ML direction during semi-tandem and tandem stances for the OTM-IL group. In these two specific conditions, subjects stood with a limited base of support, making it more challenging to maintain lateral stability.

Previous studies that have examined the effect of exercise on balance found that exercise programs designed to improve muscle strength were not as effective as task-oriented balance training, indicating that balance is highly task-specific outcome.[262,267] In a study where a task-oriented ambulation training program was compared to passive and active range of motion exercises, an improvement was found in static balance.[225] A part of the task-oriented walking program that was used in the Tsaih et al. study included similar stepping and walking exercises; however the duration of the program was shorter, which lasted for only 4 weeks, and the intensity was lower than the OTM exercise program. Due to the nature of the balance outcome measure that Tsaih et al., used (i.e., Berg Balance Scale (BBS)), it is difficult to make a comparison with our findings. Other exercise interventions have been studied to improve balance function in older adults such as progressive resistance training, multicomponent exercise, and balance training. Systematic reviews have concluded that resistance exercise interventions result in an improvement in muscle strength but not in postural control variables in older adults.[21,268] However, when adding balance exercises to the progressive resistance intervention, an improvement in static balance parameters was noticed.[269] Other studies included sensorimotor training that placed a demand on the body systems involved in the maintaining of postural stability. Hue et al.,[265] observed the effect of 12-week of physical activity program that involved sensorimotor simulation exercise. In their study, there was a reduction in postural sway after training on the foam surface with eyes open and closed. A study by Alfieri et al[270] reported an improvement in postural sway after balance, stretching, and motor coordination exercise program. However, improvement was limited to the AP displacement during standing on level surface with eyes open and closed. The magnitude of change in NPL sway while standing on firm surface with eyes open and closed that we observed was lower compared to previous studies that implemented multisensory balance exercises in older adults.[271] Therefore, including multisensory exercises that stimulate the different sensory systems (visual, vestibular, and somatosensory) was recommended when designing a balance exercise program for older adults. The lack of such exercise could explain the non-significant improvement in some of the balance conditions.[193,272] Nevertheless, the lower adherence to the task-oriented program in this study, and the fact that both the OTM and the standard exercise were slightly overlapping with both having a warm-up and strengthening components, may explain the difficulty in finding a significance differences between them.

Surprisingly, in a comparison between the standard exercise group taught by an exercise leader and the group taught by staff activity personnel, there was a difference in favor of staff activity personnel and that difference was significant during the tandem stance for ML sway. This is in contrast to our hypothesis. Although the adherence to the exercise intervention was high for both standard exercise groups, this difference may be explained by the fact that most of the staff activity personnel were familiar with the participants and the individualized feedback could have made the class more enjoyable and satisfying.[273] Another potential explanation is that the participants had greater motivation and encouragement when attending the class led by the staff instructor with whom they were familiar. The OTM-WS exercise group taught by staff personnel was not included in the analysis due to the small sample size. A comparison between OTM-IL versus OTM-WS would have validated these findings more and would also have provided greater insight into the differences noted.

The results of this study support the hypothesis that there would be no significant difference in the change in muscle strength between groups receiving an exercise intervention. Both exercise groups included similar strengthening components and that would explain the lack of difference between the groups. Although the motor learning exercise program included progressive stepping and walking patterns, i.e. altering speed, amplitude, or the accuracy of performance, that could have resulted in greater improvement in muscle strength, this would be countered by the focus or the specificity of the OTM training in correcting deficits of the muscle patterns of stepping and integrated with the phases of gait.[274] Our findings for the knee extensor and hip abductor strength improvement after the intervention were comparable with results from other studies such as after leg press strength training,[257] home-based exercise program,[275] and low intensity progressive resistance training.[276] However, our changes were lower than studies that implemented high intensity and a 12-week progressive resistance exercise.[21,277]

The improvement of muscle strength in both exercise groups was greater than that of the waitlist control group. Moreover, subjects in the waitlist group showed a decline in muscle strength from baseline. Previous studies reported a decline in lower extremity muscle strength during a detraining period.[278,279] Fiatarone et al.[277] found that a 4-week detraining period led to a significant decrease in muscle strength of 32%. Kalapotharakos et al.,[276] reported significant declines in muscle strength ranging from 60 to 87%. A 14% decline in knee extensor strength following a detraining period where subjects didn't receive any exercise intervention was reported by Ivey et al.[280] Although strength declines in these studies were during the detraining period after receiving exercise intervention, this still indicates that muscle strength deteriorates dramatically in older adults with time. In an intervention study by Khan et al.,[281] they reported a decline in knee extensor strength by 7.3% for the control group, whereas the intervention group improved. Therefore, adoption of an exercise routine is better than doing nothing in order for older adults to maintain their muscle strength.

Improvements in the ML NPL sway after the OTM exercise intervention during standing on foam surface with eyes closed and semi-tandem stance were larger than the MCID as indicated by the SEM. In addition, the change in AP and ML NPL sway for tandem stance, and only in the AP direction for foam with eyes closed was greater than the SEM. These findings suggest improvement in the aforementioned balance conditions was not due to measurement error. Thus including standing on foam surface with eyes closed, semi-tandem, and tandem stance conditions were more responsive to the OTM intervention than the rest of the included balance conditions. Additional research is needed to confirm this interpretation and examine the responsiveness of the included sway measures. All the statistically significant changes were higher than the “small improvement” cutoff as indicated by the anchor-based method. However, the drawbacks associated with current anchor in this study could limit the interpretation of the current findings. For the lower extremity muscle strength, the change in hip abductor strength was greater than the SEM for both the OTM and the standard exercise group indicating change beyond measurement error. Also, the change in the knee extensor strength was larger than the SEM for the standard exercise group only. However, the change in the ankle plantarflexor strength was smaller than the SEM for both exercise groups.

5.6 CONCLUSION

Both exercise interventions resulted in a significant change in both balance accelerometry measures and lower extremity muscle strength when compared to a waitlist control group. Although there was no significant difference when comparing the two interventions, the OTM exercise program showed a trend toward improvement in static standing balance but not in lower extremity strength.

6.0 GENERAL DISCUSSION

The main motivation behind this study was the lack of studies that have used portable and inexpensive technologies to quantify balance and muscle strength in the community, especially with individuals who live in senior communities such as independent living facilities. In this study, we intended to establish the reliability, validity, and minimal clinically important difference for static standing balance performance by using an accelerometer, and for lower extremity muscle strength performance by using a uniaxial load cell, in independent living older adults. In addition, we investigated the effect of two different exercise interventions on standing balance and lower extremity muscle strength in people who reside in independent living facilities, community senior centers, and high rise apartments.

The first aim of this study was to examine the test-retest reliability of balance and strength performance using an accelerometer and uniaxial load cell. Although the test-retest reliability of postural sway measures during static standing balance using accelerometers had been investigated in previous studies,[37,42,201] these studies were limited to clinical and lab settings. However, a study by Saunders et al.,[38] which was published after we had started this project, used a tri-axial accelerometer to quantify postural sway in people who lived in independent living facilities. Although the Saunders et al. study shared some of the same standing conditions, our study included additional standing balance conditions, and used a different foam surface. In addition, whereas the Saunders et al. study computed the root mean square, we calculated the normalized path length to quantify a different aspect of the postural sway. Saunders et al. study reported higher ICCs for RMS sway in both directions than our study, ranging from 0.77-0.93 for standing on a firm surface with eyes open and closed compared to ICCs ranging from 0.55-0.81 in the current study. Also in the Saunders study, the ICCs for standing on foam surface ranged from 0.76-0.95; our ICCs during standing on foam surface ranged from 0.52-0.77. A different methodology was used in the Saunders study that contributed to higher reliability, including that the retest session for the Saunders study was conducted within the same day. Evaluating test–retest reliability within-day has been shown to improve the ICC estimate as compared to a between-day estimation.[202] Also they used an average of three trials for each balance condition, which would increase the ICC value compared to one trial in our study. In the present study, to avoid fatigue of the elderly participants, only one trial was performed. In the current study, subjects attended two testing visits for the test–retest reliability assessment with one week apart. We found good to excellent test-retest reliability for most of the balance conditions, and strength measurements. Among the included balance parameters, the NPL sway measures in the ML direction demonstrated the highest reliability. Therefore, using an accelerometer to obtain a reliable measurement of the ML sway may provide helpful information to identify people with a high risk of falling.[92] More specifically, conditions that put more stress on the lateral stability system such as standing on a foam surface with eyes open and closed, and standing in tandem and semi-tandem stances, may more likely identify risk of falling. Furthermore, our ICC values for the sway measures were consistent with previous studies that have examined the reliability of accelerometers,[37,201,203] but lower than the ICCs in studies that have used the average of more than one trial, done the retesting within the same day, and implemented a practice or familiarization session before testing.

For the strength measurements using the uniaxial load cell device, results showed excellent test-retest reliability for all the included muscle strength tests, i.e. knee extensor, hip abductor, and ankle plantarflexor using an average of three trials. However, the reliability coefficients from the first trial were still excellent indicating that one trial is enough to obtain reliable measures. The uniaxial load cell device provides an easy and reliable way to measure muscle strength and to overcome the drawbacks that were associated with other muscle strength measurements. For example, manual muscle testing, even though it is the most frequently used technique to quantify muscle strength and is easy to use, it is susceptible to examiner's error and is subject to a ceiling effect.[44,45]

Another method that has been used in different settings to quantify muscle strength is using handheld dynamometry. Although handheld dynamometry has shown good reliability in different populations, it has some important limitations, such as difficulty in stabilizing the subject, and the reading is influenced by the strength of the examiner especially for larger muscles.[46,47] Therefore, the uniaxial load cell would provide an alternative objective method to quantify lower extremity muscle strength. The test-retest reliability was examined on only knee extensors, hip abductors and ankle plantarflexors. These muscle groups are key for standing balance and walking ability.[69] Finally, given the important relationships between falls, balance and lower extremity strength, developing low-cost and portable assessments of balance and strength are essential for monitoring the health status of older adults outside the clinic and research settings.

Another goal of the study was to determine the validity of both static standing balance and lower extremity strength performance using portable technologies i.e. accelerometer and uniaxial load cell, with mobility measurements such as the 6MWT, gait speed, F8WT, the repeated chair-stand test, GES, and SPPB. The Spearman correlation coefficients showed convergent validity between many of the acceleration measures and the SPPB, which was more evident when we examined the correlation with the balance subcomponent of the SPPB. The correlation coefficients between acceleration measures and the other mobility measurements were in the expected direction but were not as strong as that with the SPPB. However, the moderate correlation between sway measures and the SPPB indicates that different aspects of balance are being measured by the accelerometer-based measurements. The lower extremity strength measurements were significantly correlated with all the included mobility measures; however, the strongest relationship was with repeated chair-stands test, demonstrating convergent validity. These findings suggest that the accelerometer and the uniaxial load cell hold potential to be used clinically as a complementary measure to the currently used clinical balance and strength measurements, respectively.

We used multiple approaches to obtain a small range of values of the MCID as recommended in previous research.[282] Distribution-based methods were used in addition to anchor-based methods. Results from both distribution-based and anchor-based approaches didn't yield comparable results in most of the balance conditions, with results from the anchor-based method showing lower values than the standard error of measurement. As recommended by Guyatt et al.[212], the anchor should be at least moderately correlated with the instrument being examined, which was not the case in this study. In addition, the questions in the current anchor that was used did not include sway as an indicator of good balance, but instead were more about a subjective rating of balance in general. The sway measures from some of the balance conditions did not display a clear discrimination between the no change, small decline, and small improvement subgroups. Therefore, a valid and appropriate external anchor is needed in order to estimate the MCID accurately for static standing balance. On the other hand, distribution-based methods do not address the subjects' perspective of what clinically important change is. Given the aforementioned limitations that are associated with each method, I would recommend using the standard error of measurement as a threshold for meaningful change, for two reasons. First, it takes into account the precision of the measure, and it's relatively stable across populations. Second, the SEM only yields a single estimate which can be considered a reflection of meaningful change. As a result, clinicians would be more confident to interpret the change as meaningful change if a change in patient's body sway was larger than the SEM. Finally, the current results should be interpreted and used in light of the limitations that were associated with each approach.

The second aim of this dissertation was to examine the effect of two different exercise interventions, i.e. OTM and standard of care exercise, on static standing balance and lower extremity strength in independent living older adults who live in independent living facilities. There was a trend toward greater improvement in balance for the OTM exercise group as compared to the standard exercise group. However, these results may have underestimated the effect of the OTM exercise program given that the adherence to the program in this group was lower as compared to the standard exercise group. Furthermore, both exercise interventions showed a significant improvement when compared to a wait list control group, indicating that an enrollment in either exercise program would result in improvement in both static standing balance and lower extremity strength as compared to not participating in any exercise activities. Additionally, people in the wait list group showed some deterioration in some of the balance conditions and in lower extremity strength, which indicates that enrolling into an exercise program is better than doing nothing. A surprising finding was that the standard exercise group who received the exercise by staff activity personnel showed greater improvement as compared to those who received the intervention by an exercise leader, i.e. a physical therapist (PT) or physical therapist assistant (PTA). This could indicate that a person who is not certified as a PT or PTA but has had brief training can deliver the exercise efficiently. However, we could not validate this finding for the OTM exercise group due to the small sample size in the group that received exercise by staff activity personnel. The staff activity personnel may also have been familiar with the participants and that personal connection may have facilitated greater compliance with the participants.

6.1 LIMITATIONS AND FUTURE DIRECTIONS

The current work has some strengths that should be recognized. First, balance and strength performance were quantified by using reliable methods, which had been established in this specific population: i.e. older adults who live in independent living facilities, senior community, or high rise apartments. Second, we included various balance conditions that were designed to challenge and examine different balance sensory systems. In addition, we examined the reliability of testing three key muscle groups required for walking. Finally, inclusion of an active control and a waitlist control group increased the power by providing greater comparability between groups.

Interpretation of the current findings should be considered in light of the following limitations. A limitation of the current study is the sample was not randomly chosen from the parent study's sample because this was an ancillary study to a cluster randomized trial, in which we started after the randomization was done. However, baseline characteristics in our study were similar as compared to parent study. Another limitation is that we only included static standing balance conditions that have examined one aspect of the balance system. Future research that includes dynamic balance tasks such as those in the Berg Balance scale[283], and in the BESTest[284] could be done to explore if the two exercise interventions have any effect on dynamic balance. Muscle strength testing was limited to three muscle groups, i.e. knee extensors, hip abductors, and ankle plantarflexors. Although these are important muscles for maintaining standing balance and walking, other muscle groups that have some contribution to walking could have been included, such as hip extensors, knee flexors, and ankle dorsiflexors. The reason for not including them is that older adults may not have tolerated a longer testing time, given that most of testing sessions were done after they finished testing from the parent study within the same day. Moreover, excluding the OTM exercise group who was taught by staff personnel due to a small sample size prevented us from further investigation of the discrepancy between exercise leader and staff activity personnel.

In the present analysis we have examined a high number of comparisons which may increase the likelihood that the type I error is inflated. However, we didn't control for multiple comparisons to maintain power and significance level. Another limitation in the current study is the high number of drop outs. Although there was no significant difference in demographic variables between who completed the study versus those who dropped out, the generalizability of our results is limited due to the efficacy nature of the current study i.e. ideal world, where we only included those who completed the study.

For future studies, developing a representative balance anchor that can be used to determine the MCID is needed. In addition, I would like to work on the following aims: examine if the length of the balance trials of 30 seconds, as in the current study, differs from a recording of only

10 seconds. The data for this aim is available and a Matlab program to extract the first 10 seconds recoding from the total trial can be used. Another aim is to examine if the current findings for both standing balance and lower extremity muscle strength will predict falls over the course of the next year. The falls data will be obtained from the parent study. Future studies can explore more about the mechanism behind why the two exercise interventions didn’t significantly differ in terms of sway measures.

APPENDIX A

A.1 THE RMS BALANCE RESULTS ACROSS STUDY GROUPS

Table A.1: Pre- and Post-intervention change in balance performance (RMS) across groups

Balance conditions (RMS)		OTM-IL (n=28)		STD-IL (n= 33)		STD-WS (n=25)		Waitlist, n=46	
		Change [a]		Change [a]	P [b]	Change [a]	P [b]	Change [a]	P [b]
Level EO	AP	0.05	0.838	-0.62	0.538	-0.79	0.527	1.12	**0.032**
	ML	-0.24	0.616	0.46	0.604	-0.76	0.143	-0.13	0.297
Level EC	AP	-1.64	0.068	-1.55	0.153	-3.02	**0.009**	0.15	0.917
	ML	-1.30	0.065	-0.41	0.741	-0.52	0.339	-0.52	0.172
Foam EO	AP	-2.39	**0.043**	-3.63	0.098	-2.26	0.123	0.67	0.676
	ML	-3.62	**0.001**	-1.19	0.238	-2.49	0.29	-0.93	0.509
Foam EC	AP	-3.62	**0.019**	-4.32	0.079	-4.62	**0.045**	-1.70	**0.044**
	ML	-6.64	**0.004**	-4.68	**0.016**	-3.00	0.189	-3.84	**0.006**
Semi-tandem	AP	-1.92	0.219	-1.28	0.221	0.12	0.6	0.21	0.664
	ML	-1.68	**0.001**	-0.30	0.532	-1.21	0.150	-0.40	0.718
Feet tandem	AP	-4.06	**0.015**	-2.48	**0.040**	-2.74	0.121	1.04	0.472
	ML	-1.72	**0.004**	0.18	0.926	-2.50	**0.006**	-0.11	0.582

[a] Change in balance performance from baseline to post-intervention
[b] Wilcoxon-signed rank test of difference from baseline to post-intervention across groups

Table A.2: Adjusted mean change in balance performance between groups for RMS sway

Balance Conditions (RMS)		OTM-IL vs. STD-IL	OTM-IL vs. Waitlist	STD-IL vs. Waitlist	STD-IL vs. STD-WS	STD-WS vs. Waitlist
		Estimate (SE) [a]	Estimate(SE) [a]	Estimate (SE) [a]	Estimate (SE) [a]	Estimate (SE) [a]
Level EO	AP	-0.03 (0.98)	-0.77 (0.93)	-0.73 (0.83)	-0.17 (0.95)	-0.56 (0.96)
	ML	-0.49 (0.63)	-0.23 (0.58)	0.26 (0.51)	0.83 (0.57)	-0.57 (0.51)
Level EC	AP	0.05 (1.21)	-1.32 (1.09)	-1.37 (0.94)	1.08 (1.06)	**-2.45 (1.06)**
	ML	-1.09 (0.65)	-0.74 (0.61)	0.35 (0.53)	0.73 (0.60)	-0.38 (0.52)
Foam EO	AP	-0.69 (1.55)	-2.02 (1.42)	-1.33 (1.28)	0.84 (1.42)	-2.18 (1.53)
	ML	-1.72 (1.59)	-0.81 (1.39)	0.91 (1.19)	2.47 (1.30)	-1.56 (1.31)
Foam EC	AP	-1.11 (2.41)	-2.05 (2.28)	-0.93 (2.05)	1.40 (2.28)	-2.33 (2.50)
	ML	-2.10 (1.82)	-0.99 (1.63)	1.10 (1.44)	2.32 (1.61)	-1.22 (1.65)
Semi-tandem	AP	-0.72 (1.27)	-0.74 (1.21)	-0.01 (1.07)	-0.35 (1.22)	0.34 (1.25)
	ML	-0.49 (0.65)	-0.47 (0.58)	0.02 (0.49)	0.69 (0.54)	-0.67 (0.58)
Feet tandem	AP	-1.27 (1.71)	**-3.40 (1.67)**	-2.12 (1.51)	-0.08 (1.7)	-2.02 (1.86)
	ML	**-2.27 (1.04)**	-1.20 (0.97)	1.07 (0.84)	**3.18 (0.95)**	**-2.11 (0.86)**

[a] OTM-IL= On the Move immediate leader, STD-IL = Standard immediate leader, STD-WS=Standard wait staff
[b] Mean estimated group differences and standard error for changes in balance performance after adjusting for baseline values and other potential covariates. Bold font indicates significant at $p<0.05$

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